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The Utility of Meteors*

By DR. HARLOW SHAPLEY

I admit that meteors do not look useful when you see them as quick flashes in the night sky. They certainly seem to be utterly impractical. Even when the astronomer patiently tells you again that meteors are not falling stars, or shooting stars, or stars of any kind whatever; and tells you also that they are, on the average, only forty to eighty miles above the earth's surface, that they are mostly tiny specks of dust burning up through friction with our rare upper atmosphere, and that they are related to comets and to the cosmic dust clouds of the Milky Way, even then they do not seem to be particularly useful.

But that is where you are mistaken. For meteors have, of a sudden, high practical importance. They have entered the affairs of men, and that is what we rather foolishly praise as practical. On the pure science side meteors have for a long time been regarded highly. To me they appear to be so important, as clues to the origin of the universe, and as evidence of how the universe works, that we give them high priority on the research programs of the Harvard Observatory.

Before I tell you how war and technology suddenly made meteors of practical importance, I should like to build up a little background. Many listeners to this broadcast are familiar with meteors in two forms—as the flashes in the sky, and as the bits of iron and rock of odd shapes found occasionally on the surface of the earth. Some meteors are large and move so slowly, relative to the earth, that they are not completely burned up in passing through its atmosphere.

Those meteors that reach the surface of the earth we call meteorites, and the most conspicuous meteorites are collected into our museums. But only the occasional meteor reaches the earth, while literally billions of ordinary meteors strike the earth's atmosphere daily. They are tiny. Some are iron fragments, but many are mere pebbles or dust grains, so small that a thousand of them would scarcely weigh one ounce. Although they come from outer space, they are made of the same stuff as the rocks of the earth's crust.

How can such tiny particles make those bright flashes we see forty

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to eighty miles above the earth's surface? It is the speed that does it. When a dust grain from interplanetary space dashes into our upper air it may be moving twenty-five miles a second or even faster. There is so little atmosphere above one hundred miles that the onrushing meteor rarely gets hot enough to shine in those altitudes, but when it falls to about eighty miles altitude it encounters denser air, and the farther it falls the denser and more resistant the air becomes. The atmospheric friction not only generates temperatures of thousands of degrees Fahrenheit and burns the particle, but also slows it down.

Meteors are difficult to observe with precision. Any clear moonless night you can see several every hour, usually more of them after midnight than before. But they appear without warning and move so rapidly across the sky that estimates of their positions and speeds are very uncertain. Photographic observations, however, can be highly accurate, but the meteors are so swift that only the brightest ones can be recorded photographically with the fastest plates and the most suitable telescopes.

Astronomers have developed an ingenious but simple photographic way of measuring the paths of meteors, their altitudes, and speeds. Of still more importance, they can measure the slowing down, the deceleration, we call it. The principal instrument in this work is the telescopic patrol camera, which covers a large segment of sky and photographs everything that happens within a given period of time.

We get the altitude by using the surveyor's method—triangulation. The meteor is photographed from two stations, simultaneously, of course, stations separated by some twenty to twenty-five miles. As it moves across the sky, the meteor leaves a trail on each photographic plate. Careful measuring of the plates gives the angles, and simple computing gives the height above the two observing stations.

We get the speed by use of a rotating interruptor whose blades whirl between the camera and the sky. These uniformly rotating blades interrupt the exposure twenty times a second, and transform the long meteor trail into a broken line. The distance between breaks varies along the trail, getting less as the time goes on, and thus giving a measure of the slowing down. The total duration of the average meteor flash is less than a second and for that reason the rotating interruptor must cut off the light at least twenty times a second to get enough breaks for a satisfactory measure.

The slowing down of the moving meteor gives a very important result; namely, a measure of the density of the atmosphere at these great heights. It tells us also about the temperature of the upper air and how much the thin atmosphere drags on the particle. Some very surprising facts have been discovered about the temperatures and densities. For instance, it is much hotter forty miles up than at the earth's surface.

Despite important contributions, the science of meteor deceleration is

still young and much remains to be done. The Harvard Observatory is now setting up a powerful set of meteor cameras of new design at its station in Colorado, high in the Rocky Mountains, above the dustiest part of our troublesome atmosphere.

The new equipment should be about one hundred times as fast and effective as any that we have used heretofore. When these cameras are operating, instead of having to fish photographically for a hundred hours or so to get one satisfactory meteor, we hope to land a brilliant trail every fifteen minutes.

This new program should add greatly to our knowledge of the nature of the upper atmosphere and the nature of the meteors themselves. We shall find out some more about comets, too, because meteors and comets are related. In fact, comets are made of clouds of meteoric material. Some of the orbits of comets around the sun pass near the orbit which the earth travels. Many of the comets have meteoric particles tagging along behind, scattered all along their elliptical paths from one end to the other. As a result, when the earth, in its yearly trip around the sun, comes nearest to the path of a comet, it may encounter some of these straggling meteors. If there are many of them, we have what we call a meteor shower. That's what happened last October ninth. Dozens of meteors were seen every minute for two or three hours, all appearing to come from the same point in the sky, the constellation Draco.

Every August there is a fairly rich meteor shower called the Perseids. The parent comet of that meteor stream last visited the vicinity of the earth in 1866.

Other meteor streams are associated with the famous Halley's Comet, which comes in near the earth every seventy-six years. Now Halley's comet will not be here again for about forty years, since it is now in the outermost part of its orbit, quite invisible, out beyond the planet Neptune. If you are not patient enough to wait to see Halley's Comet when it comes back in 1986, I can help you out with a simple experiment. On May 4th and October 22nd of each year the earth passes near the orbit of Halley's Comet. I suggest that you watch for meteors on these nights. If on May 4th of any year you see some meteors coming from the constellation Aquarius, or on October 22nd coming from the constellation Orion, the chances are good that you have seen parts of Halley's Comet. Several thousands of years ago those tiny flashing fragments were a part of the comet itself. In the meantime the gravitational pulls by the various planets have relentlessly proceeded with the slow dismemberment of the once much greater Halley's Comet. In a million years there may be no Halley's Comet left; then only the memorial meteors in the earth's atmosphere in May and October will bring us visual reminders of the most famous comet of human history.

But how about the highly practical value of the new studies of

meteors? Well, I thought perhaps you would guess that one.

The new studies, as I have said, are going to give us accurate information on the temperatures, densities, and other properties of the earth's atmosphere at forty to eighty miles above the earth's surface. And precise information on this region of the atmosphere is exactly what we anxiously need for the development of high altitude jet-propelled airplanes, as well as for the rocket ships of the near future, and alas! for rocket bombs. The part of the earth's gaseous envelope that was formerly reserved wholly for the shooting stars has now become the region invaded by ambitious man, who no longer finds himself confined to the earth's surface and to the thick cloud-traveled lower atmosphere. He wants high-altitude wings and the meteors can help in their design and use.

Sunspot Problems Old and New*

By ROBERT S. RICHARDSON

By far the most conspicuous objects seen upon the sun's disk are the dark areas called spots; or better, *spot-groups,* since they occur almost invariably in clusters. Spot-groups range in size from tiny specks barely distinguishable from the granulations up to huge areas easily visible to the unaided eye through dark glass. The great spot-group of February, 1946, which was the largest for which we have a reliable record, covered an area equal to 112 times the equatorial cross-section of the earth.

All except the smallest spots consist of two portions which differ sharply in luminosity. The darker portion usually situated near the center of the spot is called the umbra. The umbra appears black to the eye but the effect is due entirely to contrast with the brilliant photosphere, for actually the umbra is brighter than an electric arc light. Surrounding the umbra is the lighter penumbra. Large irregular groups may include several umbrae within a single penumbra.

Large stable spots are sometimes surrounded by a light ring, which according to Waldmeier[1] is 3 per cent brighter than the photosphere. The bright ring resembles the faculae but is visible across the entire disk instead of only near the limb.

Practically all spot-groups during the early and middle stages of their life consist of two fairly well-defined clusters, separated by three or four degrees of longitude. It is customary to refer to the western member of the group as the *leading spot,* since it precedes or leads the eastern or following spot as the two are carried across the disk by the solar rotation. If the group is destined to become a large one, the two

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members grow rapidly during the first week, at the same time receding from each other until separated by 10° or more in longitude. Often the region between the two main components contains small unstable spots.

After the group has attained its maximum area, the following portion begins to break up into smaller spots which gradually diminish and disappear. In the meantime, the leading member has lost its retinue of small spots and developed into a single round stable spot which decreases slowly in area and finally disappears.

Rotation of the Sun from Long-Lived Spots

The true or sidereal period of the solar rotation can be found from observations of long-lived spots by application of the same formula used to determine the period of revolution of the inner planets, namely,

$$1/P = 1/S + 1/E$$

where in this case P is the sidereal period of the solar rotation, S is the apparent or synodic period of solar rotation, and E is the period of revolution of the earth around the sun, *viz.*, 365.25 days. The synodic period of solar rotation is about 27.3 days. Substitution of these values in the equation for S and E, respectively, gives 25.4 days for the sidereal period of solar rotation near the equator.

It is necessary to specify the latitude when referring to the sun's rotation period, since, unlike the earth, the sun does not rotate as a solid, the period of rotation decreasing from the equator toward the poles. Since spots seldom occur farther from the equator than 40°, determination of the solar rotation by this method is limited to moderate latitudes.

Table I gives the sidereal period of rotation for different latitudes. The period for the spots is taken from measures made by Nicholson and Miss Ware[2] using only single stable spots observed at Mount Wilson during four solar cycles. They found the angular rate of the solar rotation to be 0°.05 per day less than the value obtained at the Greenwich Observatory based upon long-lived *spot-groups*. The spectroscopic values are those found by Adams[3] at Mount Wilson in 1908.

TABLE I

Latitude	Spots a	Spect. a
0°	25.14	24.64
15	25.50	25.41
30	26.53	26.45
45		28.54
60		30.99
75		33.07

The Periodicity of Sunspots

On October 30, 1825, Heinrich Schwabe of Dessau, Germany, began observations of the sun in the hope of discovering a planet interior to

the orbit of Mercury. He found the changing appearance of the spots so fascinating, however, that his original plan was soon forgotten. Schwabe showed the true scientific spirit by keeping a systematic record of all the spots he could see upon the disk on every day that weather permitted observations. After twelve years of persistent observing his counts showed good evidence for a rise and fall in sunspot activity with a period of about 10 years. He published[4] a brief summary of his results but did not feel justified in announcing the discovery of a 10-year period. Not until 1843, after having observed two maxima and two minima, did he publish the momentous discovery of the sunspot cycle.[5]

For a long time Schwabe's article attracted not the slightest attention. Apparently nobody read it! When Humboldt mentioned it eight years later in his famous book, "The Cosmos," scientific recognition finally came. And then it was hailed chiefly for demonstrating that there was still something new to be found in the supposedly "exhausted" subject of astronomy!

Schwabe's discovery of the sunspot cycle, one of the most important astronomical events of the nineteenth century, was made with a two-inch telescope scarcely bigger than a spyglass.

Characteristics of the Sunspot Cycle

Ever since the time of Schwabe sunspots have been carefully and systematically observed. The longest series of observations is that begun by Rudolph Wolf[6] of Zurich in 1849, which has been continued without a break to the present day by his successors A. Wolfer, W. Brunner, and since 1945, by Max Waldmeier.

The relative sunspot numbers constitute an index of solar activity expressed by the formula

$$r = k\,(10g + f),$$

where g is the number of individual *spot-groups* upon the disk, f is the number of individual spots counted within the groups, and k is a constant which is different for different observatories. Each station is assigned a value of k which will make its sunspot counts agree as closely as possible with Wolf's original scale, for which $k = 1.00$. Thus k for a particular observatory will depend upon the size of the telescope, how carefully solar observations are made, the average seeing conditions, etc. The value of k for Mount Wilson is 0.60. If upon a certain day the observer at Mount Wilson sees 5 spot-groups in which he counts a total of 20 individual spots, his relative sunspot number for that day would be $= 0.60\ (10 \times 5 + 20) = 42.0$.

From a diligent search of all the old records available, Wolf was able to determine fairly reliable relative numbers back to 1749, and to obtain at least an indication of sunspot activity back as far as Galileo's first observations of the sun in 1611.

Statistics on sunspots such as the Wolf numbers have been repeatedly analyzed in an attempt to gain an insight into the fundamental nature of the solar cycle. Several times apparent regularities in the curve have been announced which the discoverers hoped would enable the rise and fall of activity to be predicted with accuracy far in the future, but so far none has been fulfilled.* Certain features about the solar cycle recur so often and are so well-marked, however, that they may be regarded as characteristic.

The average interval between successive minima from 1755 to the last one at 1944.3 is 11.2 years, or about one year longer than the last three cycles and the two cycles that Schwabe observed. The interval has been as short as 9.0 years and as long as 13.6 years. Sunspot activity probably has no definite period of variation in the same sense that the earth has a definite period of revolution around the sun. During the cycle the number of spot-groups undergoes large and rapid fluctuations. The smooth appearance of the sunspot curves usually shown are obtained only after taking averages over a considerable period, such as a year. Occasionally there may be a day near maximum activity when not a single spot is visible on the disk of the sun; while at minimum large groups sometimes occur.

Beginning with the maximum of 1847, the successive cycles have alternated in intensity in the order high, low, high, low, etc., in the ratio of about 7/5. If this trend continues, the cycle that began in 1944 should be low and the one following it about 1955 should be high. At the present time (January, 1947) the activity is so high that a high rather than a low maximum seems to be approaching. The high cycles are characterized by a steep rise to maximum in about four years and a gradual decline to minimum in seven years. In the low cycles the rise and fall of activity are nearly equal.

Spörer's Law of Sunspot Latitude

In 1858 Carrington[7] noticed that at minimum the spots were distinctly separated into two groups: one group confined to latitudes less than 20°, and later another group confined to latitudes between 20° and 40°. The general decrease in average latitude with the progress of the cycle was not announced until 1879 by Spörer.[8] It is generally known as Spörer's law of sunspot latitudes.

Two or three years before the end of a cycle, a few small spots may be recorded in about latitude 30°. They are so insignificant and short-lived that it is difficult to decide how to classify them: whether as spots of the old cycle in exceptionally high latitude, or possibly the first faint

*The analysis of the sunspot curve into 29 superimposed cycles made by H. Kimura in 1913 is worthy of special attention. From 1911 to 1922 Kimura's predicted curve deviated widely from that observed, but from 1923 to 1946 it has represented the general trend of sunspot activity remarkably well. See *Mon. Not. Roy. Astron. Soc.*, **73**, 543, 1913.

indications of the new cycle. Six months or a year before spots of the old cycle disappear for good, spots of the new cycle become fairly plentiful in latitudes between 25° and 35°. This zone of activity soon widens out in the direction of the equator, and as the cycle progresses the average latitude of the spots steadily decreases until at the end it is about 8°.

Minimum activity generally occurs when spots of the old and new cycles are approximately equal in number. Thus at minimum there are four zones of activity upon the sun: two in latitude 8° on both sides of the equator, and two between latitudes 25° and 35° in both hemispheres.

Spots are extremely rare above latitude 40° and also seldom are found closer to the equator than 5°. They do not avoid the region of the equator altogether, however, for many spot-groups have occurred within a degree of the equator. There is one group on record that had its leading spots in the southern hemisphere and following spots in the northern hemisphere.

Halm's Outburst Hypothesis

The irregular periodicity in sunspot activity and the wide discontinuity in latitude near minimum between spots of the old and new cycles led J. Halm[9] in 1901 to advance the hypothesis that each cycle constitutes a fresh outburst of activity wholly unrelated to any in the past. Halm's hypothesis has been recently revived by Waldmeier[10] (1935), and Stewart and Panofsky[11] (1938). The latter find that although the various sunspot cycles seem widely dissimilar, yet they have a strong family resemblance which could never have arisen from the accidental superposition of independent periodicities. According to the outburst hypothesis, we can never hope to predict the course of sunspot activity, since cycles in the past have no relation to those in the future. But fairly reliable estimates for the last half of a cycle can be made once its form has been established from the first half.

The Temperature of Sunspots

The umbra of a spot appears black because its temperature is lower than that of its surroundings and therefore emits less light per unit area. The most nearly direct way of measuring the temperature of the umbra is by comparing its luminosity with that of the surrounding photosphere. The temperature of the umbra can be calculated from Planck's law by assuming a temperature for the photosphere, and then measuring the relative brightness of umbra to photosphere for different colors.

Measures by various observers have yielded temperatures for the umbra ranging from 4300° K to 4800° K.[12, 13] The chief sources of error arise from tremors of the image due to atmospheric disturbances, particles in the atmosphere, and dust or scratches on the optical parts

of the telescope, which scatter bright photospheric light into the umbra. In fact, all the errors of observation combine to make the measured temperature of the umbra too high. Spots also differ slightly in temperature among themselves. This may account for the exceptionally low value of 3680° K that Abetti and Colacevich[14] found for a certain spot.

The Wilson Effect

In November, 1760, a large stable spot appeared upon the disk which attracted the attention of A. Wilson,[15] a professor of mathematics at Glasgow. He noticed that as the spot was carried toward the west limb, the umbra showed a displacement toward the center of the disk with respect to the penumbra. Two weeks later when the same spot came into view around the east limb, the umbra again appeared displaced toward the center of the disk. Wilson interpreted the effect to mean that spots are shallow saucer-shaped depressions or "excavations" in the photosphere, the penumbra forming slanting walls which slope down to the central umbra.

Although extensive observations have been made on the Wilson effect, its exact nature is still a matter of dispute. Chevalier[16] from measures made on photographs taken at the Zô-Sé Observatory, found an average depth for round stable spots of 450 miles. About 88 per cent of the spots selected showed the Wilson effect but there were notable exceptions, some spots showing a displacement of the umbra away from the center of the disk.

Pettit[17] in 1939 from visual measures made with a six-inch refractor found displacements in practically all of 26 spots examined near the limb. He attributes the effect to a ring of bright faculae surrounding the penumbra at an elevation of from 600 to 1200 miles above the photosphere.

Radial Velocities in Sunspots—Evershed Effect

In 1909, Evershed[18] at the Kodaikanal Observatory noticed that when the slit of the spectrograph is set across the center of a spot in the direction of the solar radius ("radial slit"), the spectrum lines in the portion of the penumbra nearest the limb are displaced toward the red, while those in the portion of the penumbra nearest the center of the disk are displaced toward the violet. The displacements cannot be detected when a spot is within about 10° of the central meridian.

The Evershed effect is readily explained as a Doppler shift due to currents flowing outward from the center of the spot parallel to the solar surface. A detailed investigation by St. John[19] revealed that gases at low levels are moving horizontally outward at about 0.6 mile per second; but at high levels in the solar atmosphere the direction of flow is horizontally inward at about 1.0 mile per second.

Abetti[20] has found the outflow at low levels to be much more irregu-

lar than the observations of Evershed and St. John would indicate, with velocities ranging from practically zero up to as high as 4 miles per second.

Monochromatic Images of the Sun

It is possible to photograph the sun in the light emitted by atoms of one element only. This may be done by isolating some large line from the rest of the spectrum by means of a narrow slit, and then moving the slit so as to build up an image of the sun in the light of this single line. The resulting photographs called spectroheliograms look quite different from the direct photographs taken in the light of all colors. The spectrum lines most often used for this purpose owing to their great width and strength are those of hydrogen and ionized calcium.

Recently filters have been constructed by Lyot, Öhman, Evans,[21] and Pettit,[22] which transmit only an extremely narrow band of colors and thus are practically mono-chromatic. With such a filter attached to a small telescope, features upon the sun can be observed visually or photographed, that formerly were visible only during a total solar eclipse or revealed by photography with the spectroheliograph.

Spectroheliograms taken in the light at the center of the H alpha ($H\alpha$) line of hydrogen reveal a structure around large spot-groups resembling the lines of force formed by iron filings around a bar magnet, or the lines of flow in a whirlpool. Near the spot there are usually bright or dark clouds of gas called flocculi. There may also be long streaks of dark flocculi on the disk not necessarily associated with any spot-group.

On the calcium spectroheliograms (K_2) the most conspicuous features are the irregular bunches of bright flocculi surrounding the spot-groups, through which the umbrae can be discerned like raisins in a cookie. The vortex structure which is often so striking on the hydrogen spectroheliograms is absent. The long dark flocculi can still be discerned but are much weaker than in hydrogen.

Magnetic Field in Sunspots

In 1896, Pieter Zeeman[23] of Holland discovered one of the most famous of the numerous "effects" in physics and astronomy.

He found that when a luminous vapor is placed between the pole pieces of a powerful electro-magnet, the spectrum lines instead of having their normal appearance are split into several components. The way in which a line is split depends upon the strength of the magnetic field and the angle at which the light is viewed with respect to the direction of the field. Now the earliest solar observers had noticed that most lines are wider in the spectrum of the umbra than the disk. In 1905, Hale[24] and his associates launched an intensive investigation of solar activity at Mount Wilson, with the result that three years later they were able to announce that the widening of lines in the spot spectrum

is due primarily to the presence of a magnetic field, as shown by the Zeeman effect. Each spot is the center of a magnetic field, the strength of which increases with the size of the spot and, to a lesser degree, with their darkness.

The Law of Sunspot Polarity

As previously noted, spot-groups almost always consist of two clusters separated by a few degrees in longitude. The direction of the magnetic field or its polarity is opposite in the leading and following members of the spot-group, like the two poles of a horseshoe magnet. Moreover, spot-groups in opposite hemispheres are of opposite polarity. In 1908, the leading spot in groups of the northern hemisphere had a polarity like that of the south-seeking pole of a magnet on the earth, and the following spot a polarity like that of a north-seeking pole. But in the southern hemisphere, the polarity of the leading spot was north and that of the following spot, south.

When in 1912 spot-groups of the new solar cycle began to appear in high latitudes, the observers were astonished to find their polarities to be the reverse of those of groups in the old cycle. At first they feared some systematic error had crept into their work during sunspot minimum when large spots were scarce, but repeated checks failed to shake their validity. This reversal in polarity of spot-groups at the beginning of a new cycle has since been observed at the minima of 1922, 1933, and 1944, so there can be no question that it is another one of the fundamental characteristics of the mysterious solar cycle.

The true period of the solar cycle is therefore from minimum to minimum when the reversal in polarity occurs, the interval from maximum to maximum being of no particular significance. The magnetic period between the appearance of spot-groups of the same polarity in the same hemisphere is twice the eleven year period.

From 2 to 3 per cent of all spot-groups are of irregular polarity; that is, their polarity is just the reverse of that of the great majority of spot-groups in a particular hemisphere during a particular cycle. These spot-groups, some of which have endured for two rotations and were large enough to be visible to the unaided eye, seem to be irregular in no other respect except that of polarity.[25]

Theories of Sunspots

In 1795 Sir William Herschel[26] proposed a theory of sunspots which from the standpoint of durability must rate as the most successful on record. He supposed the main body of the sun to consist of a dark central core which was (presumably) inhabited. Overlying the central core were two layers of clouds. The outer layer was intensely hot and bright and constituted the photosphere. Directly beneath was a dark cool layer which served the practical purpose of shielding the inhabitants from the fierce heat of the photosphere. An occasional break in the cloud

layers produced the effect called a "spot." The penumbra of the spot was the border of the dark inner layer and the umbra the solid surface of the sun itself.

The strong feature of Herschel's theory was that it provided such a good explanation for the way a large spot actually *looks* when seen under fine definition. For this reason—as well as the immense influence of Herschel's reputation—the two-layer theory held the field practically undisputed for more than half a century.

Most modern theories consider spots to be the cross-sectional area of a rising column from which the cool gases are flowing outward over the surface. On this basis, one would expect a gradual increase in intensity from the center to photosphere. On the contrary, in passing from the umbra to the penumbra—a distance which cannot exceed 10 per cent of the whole radius of the spot—the brightness increases by about 300 per cent.[27] In tracing the image of a spot in good seeing, an observer never has the least doubt where to draw in the outline of the umbra and penumbra. It would seem that astrophysicists might learn something from Sir William Herschel, by devoting more attention to these most obvious features of sunspots.

Modern theories of sunspots generally begin by trying to account for the fact that the umbra is about 1500° K cooler than the surrounding photosphere.[28] Uusually it is assumed that as the result of some disturbance beneath the photosphere a mass of gas starts streaming upward. The gas expands as it rises and does work in pushing the overlying layers aside. The energy for this work of expansion is derived from the heat content of the gas itself. When the gas finally reaches the surface it is considerably cooler, and therefore darker, than its surroundings. Friction produces a twisting motion in the rising stream, and electrons whirled in the column create the magnetic field in the umbra. The flow of gases outward over the surface causes the Evershed effect. The chief difficulty that simple theories of this type encounter is that they provide no natural explanation for the long life of spot-groups, many of which endure for weeks and months. The column of gas would be heavier than its surroundings and would tend to slow down and finally stop. Once stopped there would seem to be no way to start it up again.

So-called limited theories of this type make no attempt to account for the 11-year cycle, Spörer's law of latitude, or the reversal in polarity at minimum.

Bjerknes' "Sea Serpent" Hypothesis

V. Bjerknes[29] has proposed an hypothesis that includes all the observed features of sunspot activity.

He assumes that as a result of the difference in temperature between the surface of the sun and the intensely heated interior, circulat-

ing currents develop which become stratified in flat layers of different density. The stratification would be irregular and turbulent in character if it were not for the solar rotation, which acts as an organizing factor tending to produce a zonal symmetry of motion of the circulating gas with respect to the sun's axis.

The spots themselves arise from a great sinuous column of rotating gas or vortex beneath the surface in each hemisphere. These vortices reach entirely around the sun parallel to the equator like snakes (hence the name "sea serpent" hypothesis). The gas within the vortex rotates in opposite directions in opposite hemispheres; they move and twist about like the rapidly changing form of a smoke ring. Occasionally the vortex will twist upward and intersect the surface of the sun. The whirling motion of the gas acts like a pump, lifting hot masses of gas upward and cooling them by expansion.

Bjerknes postulated the existence of a general circulation extending from the poles of the sun to the equator. These circulating currents have a period of rotation of about 22 years. There are supposed to be two localized centers of activity which are carried along by the general circulation. A new cycle begins when one center of activity is carried outward toward the surface in about latitude 35°. During the next eleven years it is carried downward toward the equator producing spots as it goes. When some 8° from the equator, the center of activity dips below the surface and spots no longer appear in low latitudes, corresponding to sunspot minimum. In the meantime, the other active region is beginning to break out in latitude 35° producing the spots of the new cycle. These spots will be opposite in magnetic polarity to those of the old cycle, since the two localized vortices are rotating in opposite directions.

Unsöld's Modification of Bjerknes' Hypothesis

The idea of spots arising from vortices was originally proposed by Hale[30] from his studies of the magnetic fields in spots, and from actual experiments with vortices produced in a tank of water. Unsöld[31] prefers to return to Hale's original idea of spots formed from small U-shaped vortices split off from the main vortex, rather than Bjerknes' picture of the main vortex intersecting the surface. The free ends of the U-shaped vortex act as rotating pumps which cool the gas by expansion and produce spots of opposite polarity. Unsöld points out that such vortices would be more stable than those caused by intersection of the main vortex with the surface. Also, such an event would manifest itself in other ways which have never been observed.

Alfvén's Theory of Sunspots

H. Alfvén[32] has criticized the sunspot theories so far proposed in that they fail to account for magnetic fields as strong as those observed. The spots are generally regarded as gigantic whirlpools in the solar

atmosphere, but the Evershed effect indicates that the motion is mainly straight inward or outward from the spot, which does not support the whirl hypothesis. (Abetti has found evidence for a small tangential motion in the penumbra.) Alfvén objects that even if such whirls did exist it would be impossible for them to produce magnetic fields of sufficient strength. In fact, he feels that it is apparently hopeless to look for the explanation of the magnetic field in the spot itself. Rather we should start the other way around, and see if the *spot* can be the result of the *magnetic field*.

Alfvén shows that if a conducting fluid is moving in a magnetic field there will be forces produced which cause a double wave to spread throughout the fluid in opposite directions. The effect is somewhat the same as when a tightly stretched string is suddenly released, causing two waves to travel along it in opposite directions.

As the result of some disturbance at or near the center of the sun (the origin of which is left rather obscure), two waves start moving outward along the lines of force of the sun's general magnetic field, one in the northern hemisphere and one in the southern hemisphere. The theory predicts that the outgoing waves will reach the surface first in high latitude and move toward the equator with about the same velocity as the spot-zone progresses during a cycle. The time required for the wave to travel from center to surface is about forty years.

The outward moving disturbance has the shape of an anchor ring, which upon reaching the surface breaks into two parts or spots with opposite polarities. It follows as a natural consequence that spots on opposite sides of the equator will be of opposite sign. (I believe that Alfvén does not consider the origin of spot-groups of irregular polarity.) The theory encounters difficulty in explaining the reversal of polarity at minimum but apparently it can happen. Owing to the magnetic field in the center of the spot there will be convection currents flowing upward which cool the gas by expansion, whereas just outside the spot there will be currents flowing downward.

Apparent Solar and Terrestrial Relationships

It is of interest to inquire whether the sun produces terrestrial effects other than those of warming and lighting our planet. Sunspots are particularly hopeful objects for such investigations, since they vary widely in number and size over intervals of a few months as well as in periods of about eleven years. Many noted astronomers have devoted much time to the study of sunspots—not because they were interested in the spots themselves—but in the expectation of connecting them with changes upon the earth.

Of the numerous solar and terrestrial relationships that have been announced, only a few of the best established and most interesting will be mentioned here.

There is a close parallelism between terrestrial magnetic activity and sunspot activity, such that disturbances in the earth's field are more frequent and most intense and the amplitude of the diurnal variation is greater, when sunspots are most numerous. This relationship becomes apparent only when means are taken over long periods of about a year. When the means are for shorter periods such as a month the relationship is much poorer.

The earth's magnetic field is persistently most disturbed during the equinoctial months of March and September. Although this effect has been investigated in detail the cause is still unknown, but is probably due to some seasonal effect in the earth's atmosphere.

Occasionally the earth's magnetic field will be violently disturbed by a magnetic storm, which often begins suddenly and nearly simultaneously over the surface of the earth. Maunder[33, 34] and others have shown that magnetic storms can be correlated with large spot-groups more often than would be expected by chance. He finds that the most likely position of a large spot-group upon the disk with respect to the time the storm commences is from two days before central meridian passage to four days after central meridian passage. The most favored time of all is about one day after central meridian passage.

Although violent magnetic storms are associated so closely with exceptionally large spot-groups that there can be little doubt that one is the cause of the other, yet notable exceptions are known. A very great magnetic storm occurred during November 13-14, 1894, when only some small spot-groups were on the disk. Thirty-two small magnetic storms have been recorded on days when no spots whatever were visible. Conversely, naked-eye spot-groups have crossed the solar meridian without causing any appreciable magnetic disturbances. For example, during December, 1946, a naked-eye spot-group failed to cause any notable magnetic disturbance.

There is a correspondence between the frequency of auroras and sunspots similar to that between magnetic activity and sunspots. The intensity of auroral disturbances increases from low latitudes up to about 23° from the magnetic poles, so that magnetic latitude 67° is the zone of most frequent occurrence of auroras. The intensity then decreases toward the magnetic poles but still remains considerable.

Brilliant *flares* (formerly called *bright chromospheric eruptions*) seen most often near large active spot-groups occur simultaneously with sudden fadeouts in high frequency radio transmission over the daylight side of the earth. The effect was discovered as the result of research initiated by J. H. Dellinger[35] in 1935.

The flares are most easily seen with the spectrohelioscope or monochromatic filter in the light of Hα. The bright area reaches maximum intensity within five or ten minutes and then fades away more slowly. The flares show no significant radial velocity. Over an active group

several small flares may be seen in the course of an hour, but the intense flares that endure for several hours are rare indeed. During the two weeks that a large active group is in transit across the disk an observer will be lucky to witness one or two flares of major brightness.

One of the most characteristic features of the flares is that they seem always to occur near a spot-group. Out of 593 flares observed at Mount Wilson from 1917 to 1943, inclusive, only five definite examples could be found of flares that occurred where no spot-group was recorded. In three cases, however, small groups had been seen one, five, and three days before, near the position of the flares. The fact that flares of considerable intensity have been observed where no spot-group has existed for several days lends support to the idea of persistently active areas upon the sun.[36]

H. W. Newton[37] at Greenwich finds that the very brilliant flares occurring near the center of the disk are followed within two days by a magnetic storm in 82 per cent of the cases considered.

Radio exploration of the upper atmosphere shows that, in addition to the sudden changes in the ionized layers ascribed to bursts of ultraviolet light from flares, there is a general change in the degree of ionization during the 11-year cycle. Near sunspot maximum the ionization becomes so high that long-distance radio transmission is possible by much shorter wave lengths than at minimum. Apparently there is a rise and fall in the ultraviolet radiation from the sun with the 11-year cycle. C. W. Allen[38] has tentatively identified the source of changing ultraviolet radiation with the faculae, which are regions at a slightly higher temperature than the photosphere and also vary in extent with the cycle.

The most startling solar effects are the powerful radio emissions which have been observed in the 1-6 meter radio wave-length band.[39] These emissions appear to be associated with large active spot-groups, particularly the violent disturbances connected with intense flares. During these disturbances the radio emission recorded has attained values a hundred million times greater than the sun should emit if it radiates like a normal black body at 6000° K. The temperature of the solar atmosphere corresponding to these intense radio emissions is more than a million degrees.

These solar radio effects, which seem to have been first reported by E. V. Appleton[40] in 1945, open up a new and fascinating field for investigation, the results of which we dare not even guess at present.

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Measuring Halos with Stars

By CHARLES H. SMILEY and DONALD S. REED

On the evening of January 6, 1934, the first of this series of measurements of lunar halos was made by C. H. and M. H. Smiley in Providence, Rhode Island. Two bright stars were observed at the inner edge of a halo and one at the outer edge. The time and place were noted as well as the names of the three stars. Later the positions of the moon and of the three stars were obtained from the *American Nautical Almanac*. A brief computation (described below in this paper) was made to determine the apparent angular distance from the center of the moon to each star. Thus two measures of the inner radius and one of the outer radius of the halo were obtained.

At a meeting of the Skyscrapers, amateur astronomical society of Rhode Island, the routine by which the measures were made was described and it was suggested that the members might make sketches of lunar halos on penny postcards noting times, locations and names of observers, and the names of stars on the inner edge, within, and on the outer edge of the halo. If such sketches were mailed in, an effort would be made to reduce the observations and to determine accurately the dimensions of the ordinary 22° halo. The pleasure of observing was the only incentive offered; it was pointed out that only a person well acquainted with ordinary halos would recognize an unusual halo as out of the ordinary.

A number of members of the organization have mailed in sketches of halos; Mr. Reed has continued to send in observations during the twelve years to date. A sample card reporting a halo is shown in the accompanying illustration. Altogether 45 halos have been observed and 124 measures made. Of these, 106 were made by Mr. Reed and 11 by Mr. Smiley.

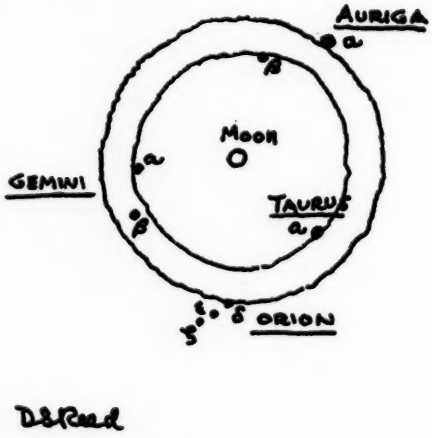

FIGURE 1

In the reduction of the observations, the Greenwich hour angle and declination of the moon and the brighter stars have been taken from the *American Nautical Almanac* of the year in question. For stars not given in the *American Nautical Almanac,* reference has been made to

"Apparent Places of Fundamental Stars," an annual publication sponsored by the International Astronomical Union. With the local hour angle, declination, and latitude of observer, the altitude and azimuth of the moon and of each of the stars have been computed to the nearest half-minute of arc by the use of Hydrographic Office Publication No. 211, Dead Reckoning Altitude and Azimuth Table, by Arthur A. Ageton. The computed altitudes of the moon have been corrected for refraction and parallax; those of the stars for refraction. With these corrected altitudes and computed azimuths, H.O. 211 has been used to compute the angular distance from the center of the moon to each of the stars, using essentially the formulae for Great Circle Distance and Initial Course. These computed distances were used as measures of the corresponding radii of the halos.

The results may be summarized briefly as follows: thirty-seven measures of inner radii yielded $21°.52 \pm °.09$; thirty-two "middle of the halo" measures averaged $23°.98 \pm °.08$; forty-five measures of outer radii gave an average value of $25°.62 \pm °.10$. Ten measures were discarded because of internal inconsistencies.

No other measures of the outer radius or "middle of the halo" radius have been found in the literature. The value for the inner radius may be compared with those given in J. M. Perntner's "Meteorologische Optik" (Wien, 1906, p. 228 ff):

Observer	Number of observations	Average value inner radius	Probable error of average
Humboldt	2	21° 33′	
Brandes	1	21° 15′	
Kamtz	8	21° 50′.4	± 2′.6
Galle	16	21° 43′.4	± 3′.5
Ekama	16	21° 57′.3	± 1′.5
Omond	16	22° 00′.9	± 2′.8
Average	59	21° 52′.2	± 1′.5

It may be noted here that the different methods used in measuring the radii of halos and perhaps different definitions of the "radius," may easily account for the variety of results shown above. In order to compare our own results with them, we need to take into account the fact that the moon has an appreciable radius, approximately 16′. The minimum deviation for deep red rays, say 6563 A, may be taken as the inner radius of the halo as determined from our measures, $21° 31′ \pm 5′$ *plus* the apparent radius of the moon, 16′, or $21° 47′ \pm 5′$ which agrees quite well with the average of the values given in Perntner.

Using the index of refraction of ice, 1.3091, which corresponds to the wave length chosen above, 6563 A, and the minimum deviation just determined, one finds the prismatic angle of the ice crystal to be $60° 02′ \pm 10′$ which agrees very well with the commonly accepted value of 60°.

Another matter which may reasonably be considered here is that of

the old superstitition that the number of stars seen inside the halo indicates the number of days before a storm. On a star map showing the entire sky, a curve representing the ecliptic was drawn in, then two curves on either side of it and 21°.5 from it. It was assumed that the numbers of first, second, and third magnitude stars within this 43° band around the sky would, on the average, be the same as in a 43° band centered on the plane of the moon's path. The count showed 9 first-magnitude stars (0.5 to 1.5), 17 second-magnitude stars (1.6 to 2.5), and 66 third-magnitude stars (2.6 to 3.5). Taking the radius of the celestial sphere as unity, the area of the 43° band was found to be 1.466π square units, and the area of the interior of a 21°.5 halo 0.139π square units. Thus on the average, one might reasonably expect .94 (one, say) first-magnitude star, 1.78 (two) second-magnitude stars, and 6.93 (seven) third-magnitude stars to be within the halo. The presence of the planets in the 43° band would increase the figure for first-magnitude "stars" slightly. The number of stars actually seen within a halo would serve as a measure of the opacity of the cirrus cloud and hence to some degree as a meteorological index.

It has often been pointed out that the high cirrus clouds which cause halos are at times the first indication of a coming storm. If it turned out that on the average, two days before a storm the cirrus clouds were heavy enough to hide third-magnitude stars but not second-magnitude stars, and one day before the storm, they were thick enough to eclipse second-magnitude but not first-magnitude stars, one would have a scientific basis for the old superstition. Actually the evidence points the other way. Cirrus clouds appear generally to thicken much more rapidly than is suggested above. Also there seems to be very little evidence that a storm follows a halo by three days or less.

The authors wish to acknowledge the kind assistance of Dr. E. O. Hulburt and Dr. E. W. Woolard, each of whom read this paper in manuscript and made valuable suggestions. In particular Dr. Woolard points out that "The value of observations is greatly enhanced, not only by large numbers, but also by data on the coloring and intensity." It is planned to continue the observation of lunar halos and to photograph solar halos in color, especially Venturi Ovals, whenever possible.

LADD OBSERVATORY, MARCH 21, 1946.

A Ten-Year Study of Mercury and its Atmosphere

By WALTER H. HAAS

Introduction

This paper is a discussion of observations of the innermost planet by a small group of largely American amateur astronomers between the years 1936 and 1945, inclusive. The group made about 230 drawings of the planet and observed it on a few dozen additional dates on which no drawings were made. The observers and their principal instruments are listed below. I made the majority of the observations, and Johnson was the most active of the others.

Observer	*Station*	*Telescope*	*Remarks*
C. F. Gramm	Rochester, N. Y.	4-in. refr.	
W. H. Haas	Alliance, Ohio	10-in. refr.	Mount Union College Observatory
W. H. Haas	New Waterford, Ohio	two 6-in. refls.	
W. H. Haas	East Cleveland, Ohio	9-in. refr.	Case School Observatory
W. H. Haas	Des Moines, Iowa	5-in. refl.	A. E. Chennell's telescope
W. H. Haas	Des Moines, Iowa	6-in. refl.	P. Engel's telescope
W. H. Haas	Upper Darby, Pa.	18-in. refr.	Flower Observatory
W. H. Haas	York, Pa.	5-in. refr.	T. R. Hake's telescope
H. M. Johnson	Des Moines, Iowa	5-in. refl.*	
H. M. Johnson	Des Moines, Iowa	8-in. refl.	
H. M. Johnson	Des Moines, Iowa	8-in. refr.	Drake Observatory
H. M. Johnson	Des Moines, Iowa	5-in. refl.	A. E. Chennell's telescope
H. M. Johnson	Des Moines, Iowa	6-in. refl.	P. Engel's telescope
E. P. Martz, Jr.	Mandeville, Jamaica, B. W. I.	5-in. refl.*	W. H. Pickering's Observatory
W. W. Spangenberg	Schwerin, Meckl., Germany	2-in. refr.	
W. W. Spangenberg	Schwerin, Meckl., Germany	4-in. refr.	
F. R. Vaughn, Jr.	Des Moines, Iowa	8-in. refr.	Drake Observatory
F. R. Vaughn, Jr.	Rochester, N. Y.	7-in. refl.	
E. K. White	Chapman Camp, B. C., Canada	9-in. refl.	

*Diaphragm on a larger telescope.

Universal Time will be used as the basis of dates and times in this paper.

Figure 1 shows some fairly typical views of the planet.

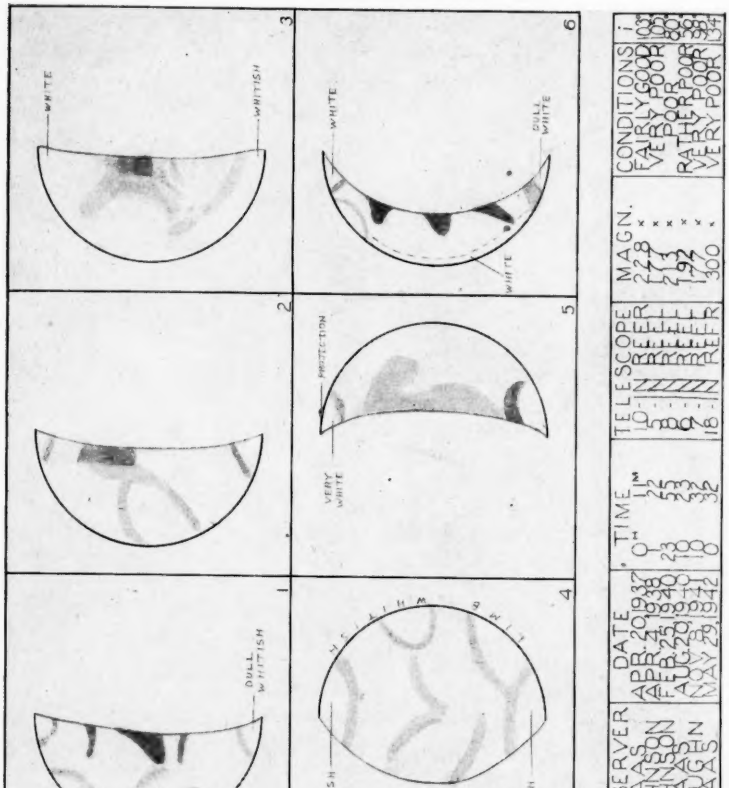

FIGURE 1
SAMPLE DRAWINGS OF MERCURY

GENERAL APPEARANCES

The cusp-regions of Mercury are usually seen whiter and brighter than the rest of the disc. These caps are bordered by dark bands. The limb is also brightened, an appearance shown especially well in some drawings by Denning.[1] A few dark spots and bands are remarked over the rest of the disc. The darkest features are those lying along the

terminator. The size and shape of the markings are very difficult to judge under the poor conditions that attend observations of Mercury, and it may well be that these dark objects really look much like the *maria* on the moon. "Personal equation" for Mercurian detail is well shown in simultaneous series of drawings by G. Fournier and V. Fournier.[2] The shadings are far more intense than those on Venus and are comparable to the *maria* of Mars in conspicuousness; some of our observers, like Jarry-Desloges,[2] have found that when Mars is studied under conditions as adverse as those regularly prevailing for Mercury, the features on Mars are then as difficult as those on Mercury. The whitened cusps and limb of Mercury further justify Denning's comparing it to Mars.[1]

Rotation and Position of Axis

Our observations give strong evidence that the planet rotates in 88 days and thus always keeps the same face sunward, on the average. In reality libration causes 26 per cent of the surface to be alternately illuminated and dark; this matter has been discussed well elsewhere.[3, 4] Attentive examination reveals the same markings in the same positions from date to date in the same apparition and also from apparition to apparition, except as their positions are modified by libration; and one gradually learns, as on Mars, to expect certain features. It is true that a day-to-day constancy of aspect when the planet is observed near the same time each day (sunrise or sunset) can also be explained by a 24-hour rotation; but on June 9 and again on June 12, 1944, I watched Mercury carefully for 90 minutes without noting *any* shift of detail such as a 24-hour rotation would have to produce; the shift of Martian features in the same interval of time is most unmistakable.

The axis of rotation is nearly perpendicular to the plane of the orbit; it differs from perpendicularity by less than 15 degrees, perhaps much less. This result follows from the fact that our observations show certain Mercurian features at about the same distance from either cusp for all heliocentric longitudes of the planet; the *great* variations in the positions of Martian objects caused by a deviation of the axis from perpendicularity of about 25 degrees for that planet are well known. Moreover, the two cusp-caps of Mercury are observed to be much the same size and shape at all heliocentric longitudes, and that fact too requires a nearly perpendicular axis if we suppose the cusp-caps to be centered on the geographic poles.

The conclusion that Mercury rotates in 88 days about a nearly perpendicular axis was first reached by Schiaparelli and has been held by such other skilled observers as Lowell, Jarry-Desloges, Antoniadi, and McEwen.[5, 6]

It may be asked why the spectroscope has not been used to determine the period of rotation of Mercury. Duncan stated in 1935 that efforts to do so had all been unsuccessful,[6a] and I know of no more recent exceptions to his assertion. One is here dealing with a small disc always

close to the sun and practically always in violent motion, these latter circumstances being an especially severe handicap for an instrument as notoriously wasteful of light as the spectroscope. It appears likely that

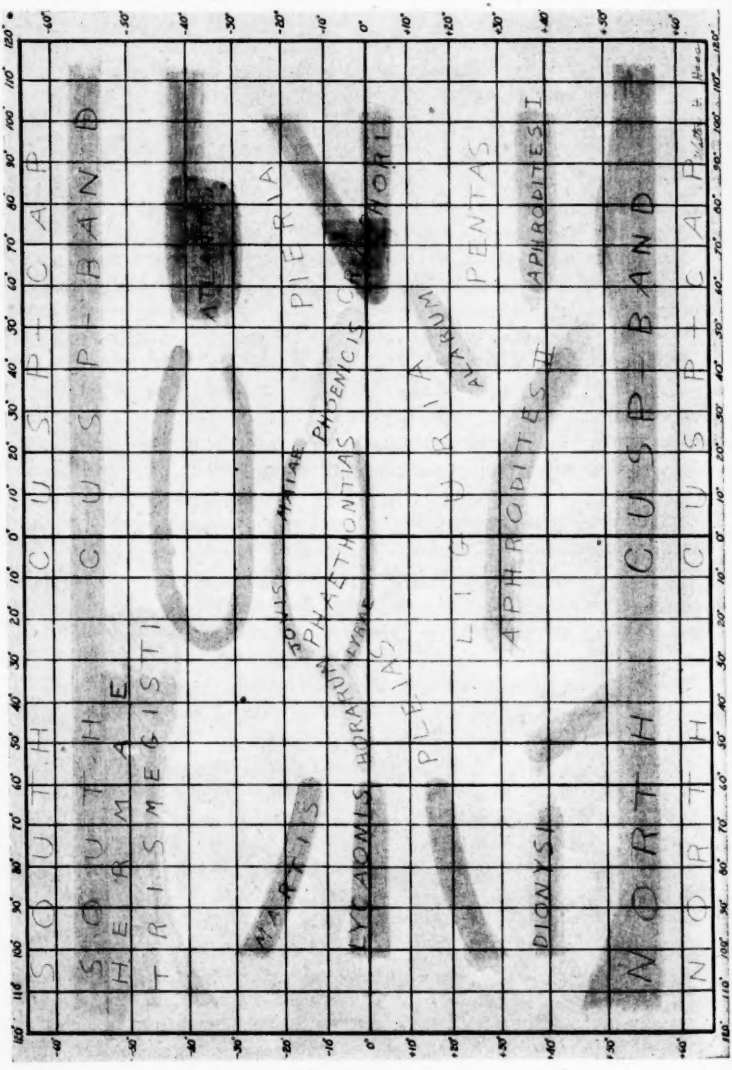

FIGURE 2
MAP OF MERCURY, BASED ON OBSERVATIONS IN 1936-45

we shall have to continue to depend on visual determinations of the rotation.

Map of Mercury

Figure 2 exhibits a map of the planet drawn on Mercator's projection with south at the top and west at the right. The objects in western longitudes are seen at evening apparitions, and those in eastern longitudes are presented at morning apparitions. The map is most reliable near longitudes 90° E. and 90° W., regions along the terminator near greatest elongations, and is very unreliable near longitude 0°, this region having to be examined under more unfavorable conditions nearer to superior conjunction. The zero meridian of longitude is the one through the center of the hemisphere turned toward the sun at perihelion and at aphelion.

The map is based wholly on the group's work. It is scarcely necessary to say that it was not easy to construct it from the available drawings, nor could subjective judging be wholly avoided where contradictions existed. I have sought to be as careful as possible and have largely followed Antoniadi's nomenclature.[6] The interested reader may wish to compare this map of Mercury with previous ones.[5] The portions of Mercury either never illuminated by the sun or else not seen illuminated often enough for sufficient study are not mapped.

Changes on Mercury

These may be considered under four heads:

1. Some changes are obviously correlated with the phase-angle i, the angle at Mercury between lines drawn to the earth and to the sun. This angle is near 0° at superior conjunction, is 90° at greatest elongation, and is near 180° at inferior conjunction. Usually observing just after sunset or just before sunrise, our group has found that detail is faint when i is small and probably grows steadily more easily visible as i increases. This effect may be due merely to the diminishing brilliance of the planet, which imitates the moon in being disproportionately bright near full.[7] We have further found that the cusp-cups grow dull when i increases above roughly 120°, perhaps merely because then narrow; Venus shows the same effect.[8] Changes of this sort are clearly not *actual* variations but merely optical effects.

2. The same object may show different aspects in different apparitions. I found the south cusp-band very faint or invisible in March, 1945, although observing with a telescope that had shown it clearly in 1942-4. I recorded an abnormally brilliant north cusp-cap in April-May, 1943, and also a conspicuously dark and thick north cusp-band, the only mark seen by Johnson and Gramm on April 24. In March, 1945, the north cusp-cap was again outstanding and was the only feature visible to White on March 27. I saw Aphrodites I (refer to map)

more easily in 1942 and 1943 than in 1944 and 1945 with the same instrument. Johnson thought the north cusp-cap and its bounding band less conspicuous in September, 1938, than they had been in September-October, 1937, a similar morning apparition during which he had employed the same telescope. Criophori (refer to map) has sometimes been seen as an extremely dark spot with a characteristic and easily recognized triangular shape and has at other times not appeared thus with the terminator in the same position.

3. A Mercurian feature may vary in aspect in only a few days. I have studied such changes by very carefully comparing the telescopic image of Mercury with a drawing made a short time before. On August 7 and 8, 1940, the north cusp-band was dark and thick; but on August 9 and later it was apparently fainter, although the general view was distinctly better. On July 18, 1941, one of the most brilliant areas I have ever seen on Mercury was remarked near the middle of the limb. This area looked smaller on July 20 and was described as "certainly vanished" on July 21. In 1943 the north cusp-band was lighter than dark spots upon the terminator on May 1, darker than these spots on May 4, lighter, on May 6, and darker again on May 10. In 1944 the north cusp-band was probably lighter on April 3 and thereafter than from March 26 to March 31. It is possible that the white limb-region shows rapid variations in appearance, but it has not been watched attentively enough to permit a definite statement. However, the reader must not be misled by the examples of changes just cited. I usually find Mercury exactly like a drawing made a few days before as nearly as can be ascertained.

4. Although the small inclination of the plane of the equator to the plane of the orbit may appear to preclude seasonal effects, Johnson and I have compared the brightness of the north and south cusp-caps, the brightness of the north and south halves of the limb-region, and the general conspicuousness and abundance of dark detail in the north and south halves of the disc. Only with the dark marks does there appear to be any correlation with the heliocentric longitude H of the planet. These marks favor the south hemisphere when H is near 135° and are most common in the north hemisphere when H is somewhere between 270° and 45°. More observations are needed, data being very scarce for H between 270° and 360°. Changes correlated with H may arise from the marked difference in the perihelion and aphelion temperatures of this planet.[3, 4]

Schiaparelli considered the spots of Mercury extremely variable; he commented on bright spots, usually on the limb, which change position and on pronounced variations, even within a few days, in the intensity of the dark features.[1, 4] The Fourniers found notable variations in the brightness of the north cusp-cap, probable changes in the tone of some dark markings, and transient bright areas.[2] Antoniadi confirmed the

findings of Schiaparelli in a striking fashion; worthy of careful study are drawings the later observer published to support his thesis that the dark areas are often paled or even completely extinguished.[4] Antoniadi further reported that the limb shows whitish arcs of a very transient character and that at evening apparitions the north cusp-cap is sometimes strikingly white and sometimes dull.[3] Finally, this observer has presented good evidence for an increase in the conspicuousness of Atlantis (see map) between 1889 and 1912.[4]

The Observed Phase

It has long been known that the phase outline of Venus is distorted by the atmosphere of that planet.[8, 9] *Careful, attentive,* and *continued* observations have revealed to our group *very similar* distortions of the phase of Mercury. We shall denote by i_1 the value of the phase-angle i when the terminator between the cusp-regions is straight, by i_2 the value of i when the cusps are in line with the center of the terminator, and by i_3 the value of i when the distance from the center of the limb to the center of the terminator is half the distance between the two cusps. If Mercury lacked an atmosphere, one would have:

$$i_1 = 90°,\ i_2 = 90°,\ i_3 = 91°,$$

to the nearest whole degree. The reason that i_3 is not equal to 90° is that the sun is not a point-source of light and accordingly illuminates somewhat more than half of the surface of a planet. Now our group has made a total of 75 independent phase-observations with numerous different telescopes at values of i between 75° and 95°, inclusive. A thorough study of these data gives as the actual values:

$$i_1 = 86°,\ i_2 = 81°,\ i_3 = 84°.$$

The value of i_1 cannot exceed 87° or be less than 84°, at least on the average. The value of i_2 is less certain and perhaps does not even differ from i_1. The dark cusp-bands *may* well cause an illusion of projecting cusps. Sometimes the terminator has been thought to show a smooth, continuous curve from one cusp to the other; and at other times the cusp-regions have been thought to project over the immediately adjacent parts of the terminator. The value of i_3 is difficult to estimate and may easily be wrong by several degrees, but it appears clear that i_3 is less than 91°. It is, however, only fair to mention McEwen's opposite result that the breadth of phase of the crescentic, but not the gibbous, Mercury exceeds its theoretical value by an amount imputed to an atmosphere about 120 miles thick.[10, 11]

The quantity i_1 was unusually large in the apparitions of July, 1939, (so observed by both Johnson and Haas) and of August, 1940; it was unusually small in February, 1940 (3 in Figure 1). There is no definite evidence of any difference between morning and evening apparitions in this respect.

These differences between observed phase and prediction for an atmosphereless planet have been reported by others in the past. They were discovered by Schroeter.[6] Beer and Maedler and Trouvelot, among others, have found the observed phase less than the predicted (*e.g.*, at dichotomy the planet is crescentic).[9]

It is well known that the horns of Venus are prolonged by its atmosphere. I have looked for a similar effect on Mercury and have made 18 micrometric measures of the angular perimeter p of the illuminated disc, all but one measure with the Flower 18-inch in the years 1942-5. The angular amount l by which each cusp is lengthened is given by:

$$l = (p - 180°)/2.$$

It is easy to show that for an atmosphereless planet at dichotomy, $i = 90°$, one has:

$$p = 180° + \tau,$$

where τ is the angular diameter of the sun as seen from the apex of the planet's shadow. Call the theoretical cusp (for an atmosphereless planet) C and the corresponding observed cusp C'; and let $\angle COC' = \phi$, where O is the center of the planet. It is true at dichotomy that:

$$l = \tau/2 + \phi.$$

Now consider, for *any* i, the spherical triangle formed by the subsolar point, S; an observed cusp, C'; and the center, L', of the dark limb. Here arc $SC' = 90° + \tau/2 + \phi$, arc $L'C' = 90° - l$, and arc $SL' = 90° + i$ if $i \leq 90°$ and $270° - i$ if $i > 90°$. With $\angle C'L'S = 90°$, one has:

$$\cos \text{arc } C'S = \cos \text{arc } L'C' \cos \text{arc } SL';$$

and this relation becomes:

$$\sin (\phi + \tau/2) = \sin l \sin i,$$

which allows ϕ to be found since $\tau/2$ and i are readily deduced from almanacs and l is determined by measuring p.

My measures were made at values of i ranging from 52° to 136°. They supply as the mean value of ϕ and its probable error:

$$\phi = 1°.9 \pm 0°.2.$$

From the observed value of i_3 one gets as the angular defect D of illumination at the center of the terminator:

$$D = -7°.$$

The above values may be checked by means of the following approximate relation: $(\phi + \tau/2)/\sin i_2 = 90° - i_2 + D + \tau/2$.

With $\phi = 1°.9$, $\tau/2 = 0°.8$ (average), $i_2 = 81°$, and $D = -7°$, the left side of this equation is 2°.7; the right side, 2°.8. The check is surprisingly good.

The Mercurian Atmosphere

Russell has proved that the prolongation of the horns of Venus is due to the diffuse reflection of sunlight and not to refraction.[12] We shall suppose that his result applies to Mercury and that a ray of sunlight tangent to the surface at a theoretical cusp C illuminates a particle at the top of the atmosphere at the corresponding observed cusp C'. The height h of the reflecting layer of the atmosphere above the surface near the cusps is then obtainable from the radius R of the planet, here taken to be 1550 miles,[13] and the ϕ already discussed. One has:

$$h = R\ (\sec \phi - 1) = 0.9 \text{ miles.}$$

It is possible similarly to obtain the height h' to which effectively opaque matter rises above the surface at the middle of the terminator by using the angular defect D of illumination there and R. One gets:

$$h' = R\ (\sec D - 1) = 11.6 \text{ miles.}$$

This h' may be much too large; for it is obviously sensitive to changes in D, which is not accurately known yet.

The fact that i_1 differs from 90° shows that the atmosphere is not uniformly clear all around the terminator but instead becomes progressively more opaque to the incoming sunlight as one proceeds from either cusp toward the center of the terminator. Some ideas of Antoniadi's[4] appear to explain this result. The large difference in temperature between opposite sides of the terminator[13] must cause strong winds to blow across this boundary. If the surface material is finely divided, and the great range in temperature to which Mercurian rocks are subject should pulverize them through differential expansion,[3] such winds would raise clouds of dust that would dim the incoming sunlight. It is finally only necessary to suppose the clouds densest near the equator to explain observed appearances.

Evidence for an Atmosphere

Since the theoretical evidence against any gaseous envelope around Mercury is usually thought very strong, it appears well to point out some of the evidence, observational and otherwise, indicating the existence of the atmosphere.

1. Theoretical calculations are usually based on the very high temperature of the reflecting surface. Far more pertinent to the question of the escape of molecules is the temperature near the top of the atmosphere. This latter temperature is much lower and hence is more favorable to the retention of an atmosphere. La Paz[14] has called attention to this important distinction, and Marshall[15] has concurred in this argument.

2. It is often flatly stated that the horns of Mercury are not prolonged as are those of Venus.[7, 13] A formula derived above can be rewritten as:

$$\sin [(p - 180°)/2] = [\sin (\phi + \tau/2)]/\sin i.$$

We shall take, for Venus, $\phi = 4°.4$ and $\tau = 0°.8$;[8] for Mercury, $\phi = 1°.9$ and $\tau = 1°.6$. The following table may then be prepared.

i	p Venus	p Mercury
90°	189°.6	185°.4
120	191.2	186.2
150	199.4	190.8
160	208.4	195.8
170	237.8	211.4
175	330.0	245.4

The prolongation of the horns of Venus is not evident when i does not exceed 120°, and the above table shows that one cannot readily see the corresponding appearance on Mercury unless i exceeds 150°. However, Mercury is unobservable with ordinary equipment at larger phase-angles; and the largest i at which our group has ever obtained an observation is only 145°. It would be of great interest to use a very large aperture to examine the horns of Mercury near inferior conjunction.

3. It has been stated that the difference between the theoretical and observed phases of Mercury is due to the faintness of the terminator and the greater brightness of the limb.[4] We have indeed found the phase very deficient on a daylight sky but have made our phase-observations near sunrise and sunset. Now if one is dealing merely with the invisibility of a faintly lit terminator, the phase should conform more closely to prediction with bright telescopic images than with dimmer ones. Our phase-data reveal no such effect. Indeed, I found for five apparitions observed with an 18-inch refractor at 300X, or 17X to the inch of aperture, an average value for i, of 83°.6; for two apparitions using a 6-inch reflector at 188X, or 31X to the inch, an average of 88°.0. It was the *dimmer* image which gave a smaller difference from the theory for an atmosphereless planet.

4. Johnson, Martz, and Haas have all found that the effect of haze, bad seeing, irradiation, inexperience in the observer, inadequacies in the telescope, etc., is to make the phase seem *too broad and too convex*. The observed distortions from prediction for an atmosphereless planet are in the *opposite* sense when conditions are more favorable.

5. I once prepared a set of pencilled drawings, spotted and shaded so as to simulate Mercury, and with the terminator drawn in as it would be on an *atmosphereless* planet at various values of i centering near 90°. The drawings were viewed from such a distance as to be about the same size as the telescopic image of the planet. I then made notes about the shape of the terminator on the various drawings, being ignorant while so doing of what the true aspect was. The experiments gave no indication that the reported distortion of the phase of Mercury is illusory but instead favored its objective reality.

6. These phase-distortions have been seen by different observers

and with different telescopes. Moreover, most of the observations employed to determine i_1, i_2, and i_3 were made *in complete ignorance* of *the value of i while at the telescope.*

7. The whitening of the limb of Mercury is very similar to what one observes on Mars and Venus, planets known to possess atmospheres.

8. The changes discussed above would not be possible without an atmosphere.

9. The measured values of the angular perimeter *p significantly* exceed what would be obtained for an atmosphereless Mercury, and many precautions have been taken to guard against a *systematic* error falsely enlarging *p*. The measures were made by placing a micrometer-wire successively tangent to the north cusp and to the south cusp. Each individual reading on a cusp was completely independent of all other readings; for the box of the micrometer was rotated 20 to 40 degrees immediately after each reading, this rotation being sometimes clockwise and sometimes counterclockwise in order to nullify any possible systematic error due to using just one direction in approaching tangency. The readings were taken on the cusps either in the repeated sequence north-south-south-north or in the repeated sequence south-north-north-south; and each separate value of *p* in a set of (usually ten) measures was thus determined by two successive readings, one on each cusp.

10. Terminator-irregularities sometimes noted by the Fourniers in 1909 and 1910[2] strongly suggest, through analogy with similar Martian marks, clouds.

Miscellaneous

On November 8, 1941, Vaughn *suspected* that a brilliant south cusp-cap projected above the limb (5 in Figure 1). An actual projecting is difficult to credit, for an angular elevation above the limb of only 0″.2 would demand a cloud or mountain rising 80 miles above the Mercurian surface; but one is reminded of Schroeter's mountains[1, 9] (perhaps also irradiative effects?).

We shall conclude with a few suggestions relating to observations of Mercury. Size of telescope is not critical here, and I have seen the planet about equally well with widely differing apertures (note the table above). Presumably the larger apertures are more handicapped by the adverse conditions always attending the observation of Mercury near sunrise or sunset and hence are not superior for this object. Filters may sometimes help the observer by dimming too bright an image. The most important thing for success, however, is *to observe the planet when contrasts are strongest;* its detail is plainest when the image is neither too pale on a bright daylight sky nor too glaring on a late twilight or early dawn sky. The period for best work is tantalizingly brief, lasting perhaps only five or ten minutes; its exact time of occurrence depends

upon such things as the aperture, the clearness of the sky, and the considerably varying stellar magnitude of the planet. It is well worthwhile to seek to obtain these elusive optimum conditions for the Elusive Planet.

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DEPARTMENT OF MATHEMATICS, UNIVERSITY OF NEW MEXICO, ALBUQUERQUE, NEW MEXICO, JULY 10, 1946.

The Planets in April, 1947

By LELAND E. CUNNINGHAM

NOTE: The time employed is Central Standard Time unless otherwise indicated. The phenomena have been chosen and described for the North American continent, and especially for the United States. The basic data have been taken principally from the *American Ephemeris and Nautical Almanac*.

Sun. In April the sun will move northward from declination +4° to +14°, and will end the month in the middle of the constellation of Aries.

Moon. The phases of the moon will occur as follows:

		C.S.T.
Full Moon	April 5	9 A.M.
Last Quarter	13	8 A.M.
New Moon	20	10 P.M.
First Quarter	27	4 P.M.

Evening and Morning Stars. Saturn will be the only conspicuous evening star; it will be near quadrature. Jupiter and Venus will be brilliant morning stars; the former will be approaching opposition. Mercury and Mars will also be morning stars, but will be too close to the sun to be conspicuous.

Mercury. Mercury will arrive at greatest western elongation on April 5. It will simultaneously arrive at aphelion, that is, at its greatest linear distance from the sun, and so its angular separation from the sun will be nearly as great as it can possibly get. During the remainder of the month Mercury will move eastward a little faster than the sun, but will not overtake it until the middle of May.

Venus. Venus will remain a brilliant morning star. During the month it will move five degrees closer to the sun.

Mars. Mars will continue its very slow motion out into the morning sky. By the end of the month it will be about one and one-half hours west of the sun, and therefore still too close for observation.

Jupiter. Jupiter will be retrograding in Libra. At the end of the month it will be within one hour of opposition. The fourth of the series of monthly occultations by the moon will occur on April 8, but will be visible only in southern latitudes.

Saturn. Saturn will be stationary in Cancer on April 3, after which it will move slowly eastward; it will be in quadrature with the sun on April 23. Its high northern declination and evening culmination combine to make Saturn an excellent telescopic object at this time.

Uranus. Uranus will be an evening object moving slowly eastward in the eastern part of Taurus.

Neptune. Neptune will be slowly retrograding in Virgo. It was in opposition on March 30.

Students' Observatory, University of California, Berkeley, February 18, 1947.

Occultation Predictions for April, 1947

The quantities in the columns *a* and *b* are given for the purpose of making these predictions useful for any place within 200 miles of the point indicated. The procedure is as follows: Subtract the longitude of the point given from the longitude of the place in question; multiply the result in degrees, taking the signs into account, by the quantity under *a* for the star to be observed; similarly, with the latitude, using *b*; apply the sum of the products, with its proper sign, to the Greenwich C.T., and obtain the predicted Greenwich Civil Time for the phenomenon at the place of observation. To obtain Eastern Standard Time it is necessary to subtract five hours; Central Standard Time, six hours, etc.

(Taken from the *Amerian Ephemeris*)

Date 1947		Star	Mag.	IMMERSION Greenwich C.T.	*a*	*b*	Angle E from N	EMERSION Greenwich C.T.	*a*	*b*	Angle E from N
				h m	m	m	°	h m	m	m	°
OCCULTATIONS VISIBLE IN LONGITUDE +72° 30′, LATITUDE +42° 30′											
Apr.	3	BD+12°2284	6.4	2 23.4	—3.0	+2.3	64	3 3.3	+0.1	—4.1	0
	3	ν Virg	4.2	23 6.3	—0.5	+0.9	104	0 10.1	—0.8	—0.2	311
	8	26 Libr	6.3	9 6.1	—1.6	—1.6	124	10 23.4	—1.2	—1.5	281
	9	10 G.Scor	5.9	4 19.6	—0.3	—0.4	146	5 25.3	—1.7	+1.0	270

Date 1947	Star	Mag.	IMMERSION Greenwich C.T.	*a*	*b*	Angle E from N	EMERSION Greenwich C.T.	*a*	*b*	Angle E from N
			h m	m	m	°	h m	m	m	°
	Occultations Visible in Longitude +91° 0′, Latitude +40° 0′									
Apr. 2	η Leon	3.6	2 46.2	−2.2	+0.5	86	3 53.4	−1.0	−2.5	332
3	BD+12°2284	6.4	1 41.9	−1.5	+0.6	100	2 53.7	−1.3	−1.4	320
3	ν Virg	4.2	22 59.2	0.0	+0.6	111	23 57.9	−0.4	+0.4	298
8	ν Libr	5.3	3 0.6	−0.7	+2.5	68	3 39.5	+0.4	−1.8	351
8	26 Libr	6.3	8 40.5	−1.4	−1.5	146	9 56.9	−2.1	−0.9	271
12	φ Sgtr	3.3	10 38.0	−2.2	+0.1	104	12 9.7	−2.2	−0.1	256
17	257 B.Aqar	6.3	10 6.6	−0.3	+1.2	97	11 4.9	−0.8	+2.2	220
	Occultations Visible in Longitude +120° 0′, Latitude +36° 0′									
Apr. 2	η Leon	3.6	1 56.1	−1.2	0.0	118	3 10.9	−1.7	+0.2	285
2	42 Leon	6.1	10 51.1	−0.3	−1.2	90	11 40.1	+0.3	−1.9	323
3	BD+12°2284	6.4	1 12.2	−0.5	+0.2	119	2 17.1	−1.0	+0.6	286
8	28 Libr	6.2	12 5.7	−2.1	−1.1	101	13 27.3	−1.4	−1.9	305
12	φ Sgtr	3.3	9 58.5	−0.2	−0.7	145	10 55.8	−2.5	+2.3	234
15	35 Capr	6.0	13 4.2	−1.7	+1.0	95	14 25.3	−2.0	+1.7	228
	Occultations Visible in Longitude +98° 0′, Latitude +30° 0′*									
Apr. 2	η Leon	3.6	2 35.5	−1.9	−1.3	129	3 59.1	−2.2	−0.9	290
3	BD+12°2284	6.4	1 34.9	−1.2	−1.2	140	2 47.2	−2.1	+0.3	278
8	ν Libr	5.3	3 46.6	−0.2	−0.1	303	8 58.4	+0.5	−4.3	186
8	28 Libr	6.2	12 49.8	−1.1	−1.5	108	13 59.8	−0.5	−1.4	284
12	φ Sgtr	3.3	10 24.7	−2.0	−0.7	128	11 47.6	−2.9	+1.1	239
24	τ Taur	4.3	2 34.2	−0.7	+0.4	49	3 19.8	+0.5	−1.8	301

*Computed by Edgar W. Woolard and Paul Herget; communicated by Commodore J. F. Hellweg, Superintendent U. S. Naval Observatory.

Asteroid Notes

By HUGH S. RICE

At this time we are able to furnish predicted positions of three asteroids for the use of telescopists. There appears to be at least a modicum of interest in these planets, inasmuch as we have been asked for ephemerides of those around magnitude 10 to 11. These requests were from observers who own 6-in. and 10-in. reflectors. However, under the best conditions, magnitude about 12 should be reached with an instrument of 4-in. aperture, but naturally observers do not find it convenient to work always at the limit of visibility. At present we have no brighter asteroids to offer than the following, all of which will get brighter until their maximum in May.

409 Aspasia. This planet was discovered by Charlois at Nice, on December 9, 1895. At that time its magnitude was 11. The discovery took place only 7 days after its opposition to the sun. It was observed for 5 weeks, and then again in 1898. Computation work was done on the planet by such well-known computers as Kromm, Giacobini, Stracke, and Boda. The mean opposition-magnitude of Aspasia is 10.7; the photo-magnitude during the middle of the period given below is predicted as 12.2. and the visual magnitude may be estimated at roughly 11.2. The orbit is inclined to the ecliptic plane by 11°.

185 Eunike. This planet was discovered by C. H. F. Peters at Clinton (probably New York), March 1, 1878. At that time its magnitude was 10.5. The dis-

covery took place only 1 day after opposition. It was observed for nearly 3 months. At one period, an interval of 16 years elapsed between observations, after which it was picked up again. A set of computers different from the preceding group was involved in the calculation of its orbit. The mean opposition-magnitude of EUNIKE is 10.0; the photo-magnitude during the middle of the period is 12.2; and the visual magnitude may be estimated at roughly 11.2. The orbit is inclined to the ecliptic plane by 23°.

57 MNEMOSYNE. This planet was discovered by R. Luther at Düsseldorf, Germany, on September 22, 1859. At that time its magnitude was 10.5. The discovery took place only 2 days before opposition. It was observed for 5 months. A set of computers different again from the preceding groups was involved in the calculation of its orbit. The mean opposition-magnitude of MNEMOSYNE is 10.7; the photo-magnitude during the mid-period given is 12.7; and the visual magnitude may be estimated at roughly 11.7. The orbit is inclined to the ecliptic plane by 15°.

The subjoined ephemerides were furnished by Dr. Dirk Brouwer of the Yale U. Observatory, with the exception of two extrapolations at the beginning.

ASTEROID EPHEMERIDES
For 0^h U.T. Equinox of 1947.0

409 ASPASIA

1947	α h m	δ ° ′
Mar. 6	15 21.3	—26 9
11	15 24.2	—26 16
16	15 26.4	—26 18
21	15 27.9	—26 17
26	15 28.6	—26 12
31	15 28.6	—26 3
April 5	15 27.8	—25 49
10	15 26.2	—25 30

185 EUNIKE

1947	α h m	δ ° ′
Mar. 21	16 31.0	+ 5 33
26	16 32.2	+ 6 20
31	16 32.9	+ 7 6
April 5	16 33.0	+ 7 54
10	16 32.6	+ 8 42
15	16 31.6	+ 9 29

57 MNEMOSYNE

1947	α h m	δ ° ′
Mar. 21	16 40.4	—11 57
26	16 41.5	—11 34
31	16 42.1	—11 10
April 5	16 42.2	—10 44
10	16 41.8	—10 17
15	16 40.9	— 9 49

Hayden Planetarium, American Museum of Natural History,
New York 24, N. Y., February 22, 1947.

METEORS AND METEORITES

Meteor Notes from the American Meteor Society

By CHARLES P. OLIVIER, President

During the past few weeks reports from our members for the final periods of 1946 have been arriving. It is specially gratifying to see that some of those who recently joined are taking an active part and that others, who had been in our armed services but are now discharged, are beginning to observe again. However,

some members are slow in reporting for 1946, so will everyone please send in whatever data remain unreported as quickly as possible, and also their dues for 1947 without my taking the time and trouble to remind them personally?

Some years before the war I loaned Professor Cuno Hoffmeister of Sonneberg Observatory in Germany about 10,000 observations by the A.M.S. as he desired to use them in a further test of his theory of daily variation, which has very important consequences, if true. He is, by the way, one of the leading experts in meteoric astronomy in the world. I recently got a belated letter from him telling me that he and my records had both survived the war safely, so eventually I hope to have them returned to our files. Meantime I trust that he will publish his conclusions based upon these independent data.

Thanks to the great shower of October 9, I have been able to secure data on a number of long enduring trains, for, while these were not numerous during the shower at any one station, still observers in various states reported at least one each. Altogether I have accounts of about 11 on that date, and also 6 others for the rest of the year. I hope to get the revised paper on this subject completed in 1947. It has been much delayed, largely by the work connected with the Draconid shower.

The present Notes are largely taken up by a continuation of reports, following those of the last two months. Even yet an occasional belated one arrives, and there are large numbers from the states alphabetically following New York, as well as from Army and Navy, still unpublished. As to the data in the table, some word should again be said about the last two columns which contain rates and number of observers. Where the rate has meaning it is given, usually for one observer. If it is for more than one the last column makes it clear. When in ( ), the rate is the maximum. It is quite impossible to take space to specify over what interval the maximum rate was recorded. In many instances it lasted for 5 or 10 minutes only, building up slowly, but decreasing far more rapidly. In other cases, where the counts are given by hour or half hour intervals, it is impossible to give the time of maximum closer than ± 30 or ± 15 minutes, respectively. Also I feel badly about not mentioning the name of each student in the various schools. In this paper there are, for instance, three cases of 24, 18, and 8 individuals, respectively. To mention each name would greatly increase the length of the table without much gain. In the final discussion these comprehensive reports from schools and colleges will be specially valuable and I assure each participant that we appreciate his aid. In all cases in these Notes, the student who observed longest and secured the greatest number of meteors, is mentioned in the line below the general report for the school. The total for the school is hence the sum of the two figures in column 6. In column 9, d indicates that each meteor was fully described on a regular record sheet.

Station and Observer	Direction	Began	Ended	Max.	Min.	Met.	Fac.	Rate Unc.	Obs.
Kentucky									
Louisville CST									
Strull, C.	NW	7:00	10:45	9:50±	225	856	0.3	228 (484)	1
Moore, W. L.		7:05	10:40	9:58	110	527		(1332)	1
Loos, G.		7:05	10:40	10:08	110	490		(1248)	1
Aker, L.		7:55	10:40	9:58	85	373		(1076)	1
Moore, C.		9:55	10:40	10:08	20	273		(1224)	1
Moore, K.		8:40	9:00		10	33			1
Average max. of 4 obs. above				10:02				(1170)	1

Station and Observer	Direction	Began	Ended	Max.	Min.	Met.	Fac.	Rate Unc.	Obs.
Kentucky									
Owensboro									
Curie Science Club of H. S.	NW-NE	6:00	17:10	10:05	670	1936	0.2		24
Johnson, Miss B.	N	8:35	9:45	9:30±	70	3371	0.2	2889	1
								(3622)	
Louisiana									
Baton Rouge CST									
Rense, W. A.	all	7:00	17:00	10:05	440	1458	0.3		6
								(471)	1
New Iberia									
Case, Miss G. C.	NW	9:45	9:55	9:50	10	106	0.4	636	1
Maine									
Augusta									
Science Club		8:40	11:40		180	1362	0.2		14
Saco									
Graves, Mrs. P. E.	N	10:50	11:20		30	112	0.1	224	1
In "Northern Maine"									
Tyson, R. A.		10:30	11:30		60	"hundreds"	0.1		*1
Massachusetts									
Boston									
Smith, F. W.		6:00	6:30		30	0	0.2		1
Michigan									
Detroit EST									
Hillebrand, J.	N	9:25	11:15	10:50	110	314	0.3	171	1
								(456)	1
Marsinko, W.	N	9:30	10:10		40	76	0.3	114	1
Drayton Plains									
8th and 10th Grade Public School	all	8:30	11:30			1245	0.3		18
Carter, Bill	NNE				150	6500	0.3	2600	1
Flint EST									
Larmayge, F.	N	8:00	12:00	11:05		2277	0.3	569	1
								(2180)	1
Grand Rapids									
Baldwin, R. B.		7:30	11:20	10:32	85	294	0.3	207	1
								(864)	1
Kalamazoo EST									
Lorey, Miss A.		10:30	11:00		30	725		1450	*1
Student in J.H.S.		10:00	10:30		30	513		1026	1
Bryant, A.		8:30	11:12	10:59	145	589	0.3	225	1
								(535)	1
Persons, W. J.	NW-NE	9:30	12:20	10:45	150	1666	0.3	666	1
Persons, Mrs. W. J.	NE	9:30	11:20	10:45	60	983	0.3	983	1
								(2520)	1
Lansing EST									
Doelle, W. H.	SW-N	10:30	10:45		15	330	0.4	1320	1
Kellogg, R. D.		10:01	10:43		30	812		1624	1
Darling, B.		8:10	12:52	10:45	137	1041	0.4	450	1
								(1708)	1
LaSalle, L. B.	Z, W	10:40	10:50		10	269		(1616)	2
Burbank, H. D.	NW	9:50	10:05		15	97	0.2	388	1
Sly, Mrs. M.	W	8:30	9:30		60	44	0.1	44	1
Trumpour, Miss V.		10:00	10:30		30	18	0.1		2
Muskegon									
Elliott, Mrs. P. A., and 6th Grade Class		9:30	11:00		90	1845	0.2		23

Station and Observer	Direction	Began	Ended	Max.	Min.	Met.	Fac.	Rate Unc.	Obs.
Minnesota									
Minneapolis									
Landon, R. H.	N	9:50	10:00		10	102	0.3	612	1
Northfield									
Gingrich, C. H.		10:05	10:22		17	100	0.2		3
Tyler									
Margandy, Miss G. E.	Z, E	9:00	9:15		15	50	0.2	200	1
Missouri									
Clinton									
Boxell, A. R.	NW	6:45	11:00		75	515		412	1
Radford, D.	NW	8:00	11:00		180	3000		1000	1
High School group	all	6:30	11:00			5588			23
Crocker									
Waddell, W. E.		9:30	10:00		30	600	0.4	1200	*1
E. Prairie CST									
Bright, Mrs. D.	NW	9:30	10:00		30	218	0.2	436	1
Hollister									
Hall, E.	NE	9:35	9:45		10	75		450	1
Kansas City CST									
Crawford, Mrs. P.	S	8:00	8:30		30	60		120	2
Earnshaw, E.		8:00	10:00		120	1073	0.3	536	1
Bowman, E. F.		8:05	9:10		65	524	0.4	485	1
		9:40	10:10		30	204	0.2	408	1
Bowman, Mrs. E. F.		9:10	9:40		30	365	0.2	730	1
Moberly									
Jones, Miss M. W.	N	9:45	10:15		30	530	0.3	1060	1
Nevada									
Norman, C. C.		9:15	9:45		30	167	0.2	334	1
Republic									
Willis, C.	NW	7:30	10:20		140	1003	0.3	430	1
Springfield CST									
Duck, Miss V.	NW	9:00	12:00	9:30±	180	806	0.3	269	3
Stone, M. C.	NNW	8:40	10:12		20	86	0.3	258	1
Willingford, C. C.	NW	7:30	10:00	9:42			0.2	(960+)	1
Leffler, F.					30	851		1702	1
Stockton									
Wright, M.		7:45	8:30		45	250		333	2
Montana									
Havre									
Kardell, V.	N	8:10	8:20		10	336	0.4	2016	1
Plecius									
Voss, Mrs. C. M.		8:00	9:00		?	175			1
Nevada									
Washo Co.									
Hays, J. C.		7:15	9:15<	9:15			0.4	x	1
Reno PST									
Tannenbaum, B.	E	7:50	8:00		10	520		3120	1
Univ. of Nev. group	all				5	485		5820	4
Univ. of Nev. group	all	7:20	7:25		5	360		4320	3
Univ. of Nev. group		7:20	7:25		1	178		2136	1
New Hampshire									
Bow Lake									
Dupee, Mrs. H. E.		9:35	12:50		180	18	0.0	d	1
Center Harbor									
Paddleford, Mrs. F.	N	9:15	10:45	9:45	90	101	0.2		1

Station and Observer	Direction	Began	Ended	Max.	Min.	Met.	Fac.	Rate Unc.	Obs.
New Mexico									
Las Vegas MST									
Lowrie, D. C.	NW	8:20	8:30		10	298		1788	1
" "		9:25	9:35	8:45±	10	106		636	1
In plane									
Haas, W.				8:52				(6000)	2
North Dakota									
Bismarck									
Johnson, Miss K.	NW	9:21	9:31		10	117		702	1
New York									
Bronx EST									
Feldman, Miss E.	NW	10:30	11:30		60	9	0.1*		1
Canandaigua									
Landman, Mrs. E. C.	NW	10:15	11:05		50	511	0.3	612	1
E. Syracuse									
Shelly, C. W.		10:00	11:00		60	500	0.2		3
Syracuse									
Montgomery, W.		10:45	11:15	10:52	23	244	0.2	(784)	1
Geneva									
Smith, C. W.	N	10:33	14:30	10:38	160	632	0.3	(1140)	1
Rogers, A. G.	NW	10:15	11:20	10:45	65	322	0.3	(468)	1
Massena									
Eriksson, H.	NE	9:30	10:45	10:38	75	760	0.4	608	1
								(1368)	
Orchard Park									
Kemble, R. C.		10:05	11:00	10:55	50	747	0.2	900	2
								(1314)	
Oswego									
Nickolas, E.		10:00	11:30	10:45±	90	786		524	1
								(908)	
Rochester									
Stevens, P. W.	N	8:30	9:36	10:52	66	81	0.2	74	1
" "	N	10:15	10:45		30	420	0.3	840	1
" "	N + S	10:50	11:25		35	371	0.3	636	1
" "	N	11:25	11:50		25	55	0.3	132	1
" "	all	9:40	10:15		35	218	0.3		4
								(1584)	
Nazareth Academy									
Bidini, Miss P. N,	NW	9:30	11:45		135	1956		868	1
Sister C. Frances group		9:30	10:58	10:44		1366		(1020)	8
Utica									
Firsching, F. H.	N	10:40	11:45		45	95	0.1	127	1

*1+

Flower Observatory, Upper Darby, Pa., 1947 Jan. 24.

Contributions of The Meteoritical Society

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Edited by FREDERICK C. LEONARD
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A Possible Meteorite Crater in the Aleutians*

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ABSTRACT

Neither theory nor the results of numerous observations made from military and commercial aircraft support the generally accepted belief that meteorite craters will prove to be quite easily discoverable by search from the air. As an indirect result of a campaign to discover new meteorite craters by *air* search, a possible meteorite crater on Amak Island in the Aleutians was reported by Charles Keenan, Second Batallion, 53rd Infantry, a member of the United States *Ground* Forces. All details concerning the location and nature of this Aleutian crater so far made available to me are presented in this paper.

§1. *Introduction.*—It seems to be a quite generally accepted belief that meteorite craters, even the smaller and therefore presumably more numerous ones, should be easily discoverable by search from the air. I myself held this view when I entered military research work for the Office of Scientific Research and Development in January, 1943. Both while stationed at the New Mexico Proving Ground, and, later, while serving with the Operations Analysis Section, Headquarters Second Air Force, I frequently made long flights in military and commercial aircraft. On all such flights I watched, whenever free of other duties, for new meteorite craters, or carefully checked on the varying aspects and degrees of visibility of recognized meteorite craters. I also sought to interest all AAF personnel with whom I came into contact to do likewise. A number of AAF officers and operations analysts participated for longer or shorter periods in the campaign for the discovery of new meteorite craters by air search. Most of these observers reported directly to me, but the observations of a few who independently initiated and carried on their own search for such craters have reached me indirectly, in one way or another. The present paper summarizes the known results of this campaign, presents certain theoretical and observational grounds for the failure of the campaign to reveal any authentic new meteorite craters, and treats in detail one possible meteorite crater in the Aleutians whose discovery became known indirectly as a result of the campaign in question. This Aleutian crater was reported NOT by an airman, but by Charles Keenan, a member of an infantry battalion. Evidently in meteoritics, as in war, the foot soldier continues to play an important role, even in the Air Age!

§2. *Results Obtained in the Air Search for Meteorite Craters.*—In this section we shall give, in alphabetical order, the names of the relatively few observers who not only participated in the campaign to discover new meteorite craters from the air but also reported the results of their searches in sufficient detail to justify

*Read at the Ninth Meeting of the Society, 1946 September.

reproduction.

(1) Colonel D. M. Barringer, Jr., Chief, Statistical Control, Headquarters Second Air Force, continued during World War II to watch for new meteorite craters while flying, as had been his practice for many years. No new craters have been discovered by Colonel Barringer during his searches, but two craters at first suspected of being meteoritic—one near Lordsburg, New Mexico, and another in southeastern Arizona—turned out to be volcanic in nature.

(2) Mr. Harold Berger, Operations Analyst, Headquarters Second Air Force, told me that, in over 600 hours of flight on B-17's and B-24's, he had never seen anything identifiable as a meteorite crater.

(3) Captain R. S. Dietz, AAF, reported to me that he had seen nothing identifiable as a new meteorite crater during his many hours in the air. It is true that in communications to me, and in a recently published note,[1] Captain Dietz favors the view that the Kentland, Indiana, "cryptovolcanic structure" is of meteoritic origin, but his opinion rests on the results of ground search, not of air reconnaissance. Specifically, Captain Dietz has discovered and photographed certain very remarkable "shatter cones" at the Kentland structure and has observed that these cones are "oriented with their apices toward the top of the beds, suggesting that the compressive deforming force came from above," *i.e.*, that it was the result of meteoritic impact.

(4) Captain Walter Huston, AAF, reported, thru Mr. Walter H. Haas, of the Institute of Meteoritics, University of New Mexico, that, in several hundred hours spent in watching for traces of meteorite craters while flying over the Plains States, he had not once found anything "that seemed worthy of serious investigation." Captain Huston's description of his search technique makes clear that he circled any suspicious object, and, if necessary, lost altitude in order to insure its identification. This highly desirable practice was not possible for many of the observers participating in the air search for meteorite craters.

(5) Dr. Joseph Kaplan, Chief, Operations Analysis Section, Headquarters Second Air Force, reported that he had seen nothing identifiable as a new meteorite crater during his frequent flights from coast to coast and along the Pacific Coast from Southern California to Seattle.

(6) Dr. Helmut Landsberg, Operations Analyst, Twentieth Air Force, gave a similar negative report based on many long flights, not only in the United States of America but also in the European and Pacific theaters of operation.

(7) Dr. Lincoln La Paz, Technical Director, Operations Analysis Section, Headquarters Second Air Force, during approximately 200 hours of flying, saw only one group of craters suspected of being meteoritic. These craters were glimpsed on 1945 June 6, in western Indiana, approximately 60 miles SSE of Kentland, while he was flying under bad weather conditions. They were never seen again and are believed to have been old, roughly circular strip pits with diameters of 100 feet or less. However, their resemblance to the low-rimmed crater at Odessa, Texas, with interior overgrown with brush and small trees, was startling.

(8) Captain Myron Roth, AAF, reported "rounded ponds in chains seen in South America." However, a study of photographs of the region flown over strongly suggests that the ponds were sinkholes like those seen in profusion near Odessa, Texas.

(9) Mr. J. Russell, of the New Mexico Proving Ground staff, reported "many pits 100 to 500 feet in diameter and 40 to 50 feet deep, approximately 60 miles north of Bay City, Michigan." However, these features appear to have been merely slump pits in sand.

(10) The following persons, all of whom had flown very extensively, reported to me that they had seen nothing identifiable as a new meteorite crater: Colonel K. H. Kalberer, Headquarters Second Air Force; Dr. H. F. Dana, and Messrs. A. E. Bennett, Ward McLaren, and Charles Foley, Operations Analysis Section, Headquarters Second Air Force; and Warrant Officers H. S. Carmichael and George Johnson, Headquarters Second Air Force.

§3. *Possible Explanations of the Failure of Air Search to Result in the Discovery of New Meteorite Craters.*—A moment's reflection on the multitudinous duties (and distractions) to which officers and men alike were subject during combat flights will explain the dearth of reports on searches for new meteorite craters overseas. Furthermore, observing conditions were no more favorable in the training air forces. This fact will be better appreciated if we recall that the United States lost more flying personnel in training than in combat! Again, the vast number of frames exposed over the United States on photo-intelligence training missions for the most part shows only in monotonous repetition the same restricted terrane, and that chiefly in and around metropolitan areas (regions where craters are unlikely to exist[2]), for such areas were to be the targets of the air-reconnaissance groups over Germany, Italy, and Japan. It seems most probable that the "shots" taken actually during photo-intelligence work overseas would furnish a more diversified and fruitful field for study, but, to date, it has not been possible to subject any large amount of combat film to close scrutiny. It is my conviction that, in all probability, any discoveries of new meteorite craters thru AAF activities will result from the study of combat "shots" taken overseas, for the K-24's functioned when visual observation was impossible, and, furthermore, the majority of air-reconnaissance photographs are "obliques," and hence are taken under the conditions most favorable to the photographic discovery of such relief as is exhibited by a rimmed depression like a meteorite crater.

As regards observing conditions on commercial flights, it may at first seem that they are ideal. However, closer scrutiny belies this conclusion. In the first place, those connected with the AAF did not take even commercial flights for pleasure, and were frequently too preoccupied with necessary duties effectively to watch for possible meteorite craters; *e.g.*, one cannot simultaneously watch *up* for Japanese paper balloons at 50,000 feet and watch *down* for craters on the ground! Again, many commercial flights were made under weather conditions precluding observation of the ground flown over; and uncleaned windows and drawn blinds and the absence on commercial planes of such ideal observing stations as the plastic noses of the B-17 and the B-29 forced the observer to work under conditions of poor visibility. However, all of these factors taken together were probably not as prejudicial to the success of air searches for meteorite craters as the single fact that all commercial flights (as well as most military missions) are flown at relatively high altitudes. This statement is justified by the analysis given below.

The presence of a rim or remnant thereof is a necessary, altho, of course, not a sufficient, condition for a depression to be a meteorite crater. Furthermore,

the most easily perceived characteristic feature of a meteorite crater is its rim. Hence, if we want to maximize the chances for discovery of a meteorite crater from the air, we should fly so as to maximize the visibility of the crater's rim. The truth of this remark will be made evident to anyone who studies two photographs of the same meteorite crater, *e.g.*, the one at Odessa, both taken under the same conditions, save that one is a vertical view down on the crater, under which condition the rim relief vanishes, and the other is an oblique view of the same object. Admittedly, under certain conditions, there are other features that serve to identify a meteorite crater as seen from a plane; *e.g.*, from the air, the Odessa Crater stands out as a peculiar, light-colored splash in the drabness of the West Texas desert. Obviously, however, such a color criterion fades out in certain lights and would lose its value if the neighborhood of the crater supported a grass or brush cover. Again, the curious, low, radial ridges (percussion rays), extending out spoke-like from some of the Henbury, Australia, craters, described by Alderman, would be quite invisible under even a slight vegetative cover. On the contrary, under almost all conditions, rim relief, or the shadow cast by the rim, is visible.

In what follows we shall consider an idealized version of the problem of maximizing the visibility of the rim of a meteorite crater. In Fig. 1, let CT

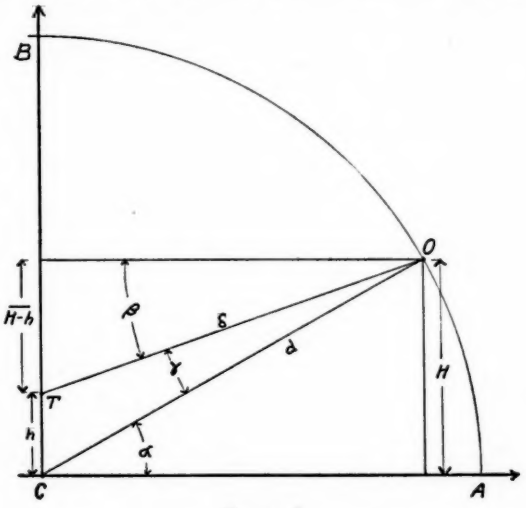

FIGURE 1
GEOMETRIC CONDITION FOR RIM-VISIBILITY

represent a "rim" of height, h, but of no apparent thickness. This "rim" is observed from a plane O whose distance from C is required to be a fixed and not too large number of miles, d. The locus of an airplane, O, flying perpendicularly to the plane of the paper, ABC, and moving so as to satisfy the distance condition just specified, is the quadrant, AOB. We seek to determine for what position of O on this quadrant, *i.e.*, for what value of the height, H, of the airplane above the horizontal plane thru C, the angle γ subtended at O by the segment CT is a

maximum. We attack this problem by attempting to maximize $\sin\gamma$, an increasing function of γ, expressed as a function of H. Now

$$\sin\gamma = \sin(\alpha - \beta) = h\sqrt{d^2 - H^2}/\delta d.$$

But

$$\delta = \sqrt{d^2 - 2Hh + h^2}\ ;$$

whence, for *fixed* d and h,

$$\sin\gamma = f(H) = [(h/d)\sqrt{(d^2 - H^2)/(d^2 - 2Hh + h^2)}].$$

It is easy to verify that the only admissible, critical value is $H = h$ and that this value of H actually maximizes $f(H) = \sin\gamma$. But this result shows that, on typical military and commercial flights, which are habitually flown at altitudes, H, much greater than h, what may be termed the *geometric condition for rim-visibility* is very unfavorable indeed. Conditions for observing rim-shadow would at first sight appear to be somewhat more favorable on high-altitude flights, but experience based on a vast amount of photographic air reconnaissance, which has resulted in a premium on good low "obliques," suggests that many factors besides the geometric enter into the detection and interpretation of object-shadows.

It is believed that the various factors discussed in this section afford a rather complete explanation of the failure of the air search campaign to reveal new meteorite craters.

§4. *The Keenan Crater.*—In the summer of 1943, Dr. J. A. Hynek, now the Director of the Emerson Macmillan Observatory at the Ohio State University, visited the New Mexico Proving Ground on a military mission, and, while observing experiments at the University of New Mexico relating to the possibility

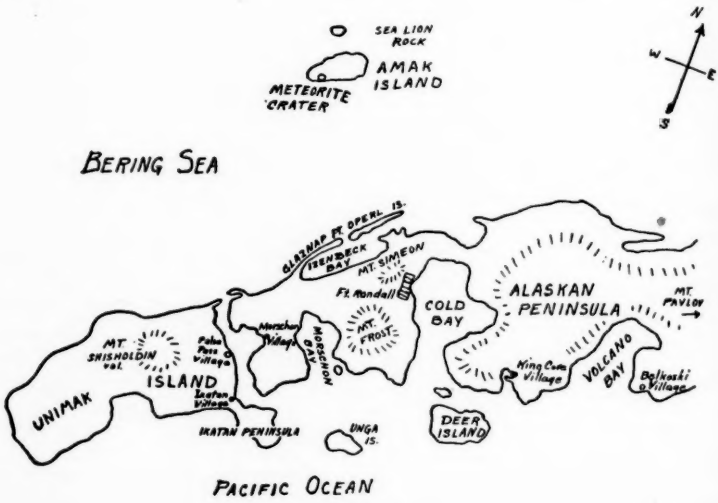

FIGURE 2

MAP SHOWING THE RELATION OF AMAK ISLAND TO THE ALASKAN PENINSULA

of the existence of contraterrene meteorites, was informed concerning the campaign to discover new meteorite craters by search from the air. On 1945 November 23, Dr. Hynek wrote me that a previously unreported meteorite crater had been found in the Aleutians by Dr. P. C. Keenan's brother (of all things not an airman, but an infantryman!). On November 27, I wrote Dr. Keenan as follows:

> "Dr. Hynek has just informed me that your brother discovered a meteoritic crater on the Island of Amak in the Aleutians. As you are aware, the scientific importance of such a discovery is great; and it is most desirable that accurate, detailed information concerning such a find be made a matter of record at the earliest possible moment. . . . . .
>
> "Details as to how to reach the crater would be invaluable. In case I am transferred from the Operations Analysis Section, Headquarters Second Air Force, to the Eleventh Air Force, it might be possible for me to visit the crater in the not-distant future. In any event, there is always the chance that an expedition to the crater could be financed by the Institute of Meteoritics of the University of New Mexico. Hynek's statement that the sea is rapidly encroaching upon the crater emphasizes the need for haste in arranging for its study, and, for that matter, in making its existence a matter of record."

On November 30, Dr. Keenan replied, sending a map tracing (Fig. 2), showing the location of Amak Island with respect to the Alaskan Peninsula and stating that there was no definite evidence of the meteoritic nature of the crater, since

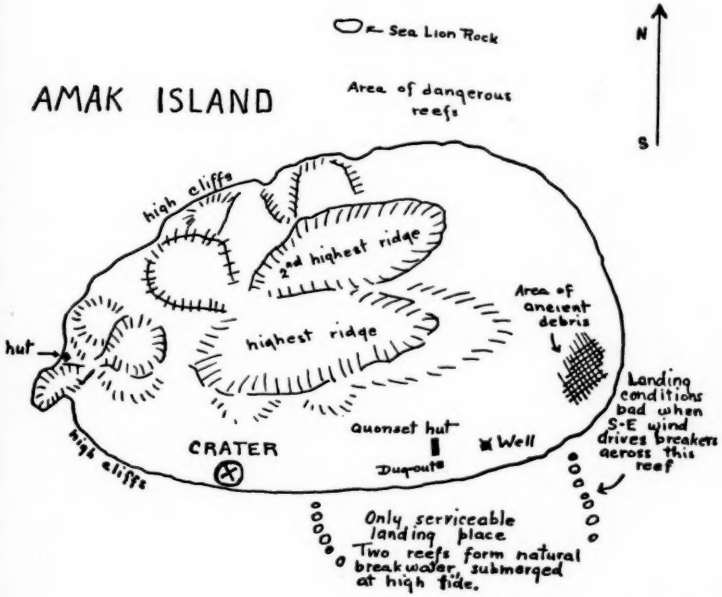

FIGURE 3
MAP OF AMAK ISLAND SHOWING THE LOCATION OF THE POSSIBLE METEORITE CRATER

a thick layer of frozen moss and surface water precluded search for meteorites. Nevertheless, it appeared from Dr. Keenan's letter that the Amak Crater, tho on a smaller scale, bore a general resemblance to the Canyon Diablo, Arizona, Crater, and that Amak Island was devoid of definitely volcanic cones. A promised detailed report from Charles Keenan, the discoverer of the crater, was therefore awaited with interest. On December 8, this report was sent me by Mr. Keenan, accompanied by a map (Fig. 3), showing the location of the crater and certain other features on Amak Island, and a diagram (Fig. 4), giving a cross-section thru

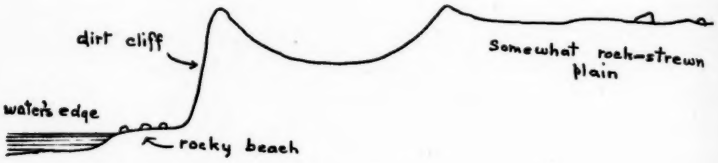

FIGURE 4
PROFILE OF THE CRATER ALONG A NORTH-SOUTH LINE

the crater by a vertical plane perpendicular to the strand line. Mr. Keenan's report on the crater, its surroundings, and the relative inaccessibility of Amak Island is quoted in full below:

"The crater itself is roughly 70 yards in diameter and 50 feet deep. It is located on a narrow, rolling tundra plain that extends between the large mountain that occupies the center of the island and the beach. It is so close to the water's edge that by now erosion has probably reached its rim. In the fall of 1943 it was separated from the seaside cliff by a partition of only one foot in the narrowest place; however, the matted moss and grass were holding it securely in place. This diagram in section will show its general situation. Like the plain, the whole surface of the crater is thickly covered by moss.

"The large rocks that dot the plain are, I believe, identical with those that form the mountain, which is unlike any other mountain I have ever seen, in that it is nothing more or less than a huge pile of loose rocks. Some are of enormous size, but apparently none on the surface is in place. On account of my ignorance of rock types, I cannot give any satisfactory description of these scattered boulders except that they were dark brown in color and some seemed too far from the mountain to have rolled down its sides. Since the tundra is several inches thick, no small fragments were visible in the neighborhood of the crater.

"From my casual observation I would unhesitatingly affirm that the crater was caused by a falling object; however, there remains the possibility that it may have been a piece blown from a nearby volcano, there being two, one about 50 and the other 60 miles distant; also there are the remains of an exploded volcano about 40 miles away.

"At False Pass Village there live a Mr. and Mrs. Gardner who undoubtedly know of this crater's existence and whether or not any similar ones are to be found in that district, as surely would be the case if there had been a shower of such giant chunks from the exploded volcano. In my two years spent around the end of the peninsula I saw only that one, but Mr. Gardner's detailed knowledge of that entire country exceeds mine by many times; in fact, he served as a guide for Father Hubbard in some of his explorations.

"I will write the Gardners at once, requesting that they send direct to you any information they may have on the subject. However, False

Pass is so badly isolated during the winter months that an answer will be a long time in coming.

"Incidentally, storm conditions are so severe until late in May that Amak can be reached only with a certain degree of danger. It is not completely inaccessible during the winter, but may become that way at any moment of any day and stay so for weeks. Boats larger than cannery tenders and fishing boats cannot cross the bar at the northern end of False Pass, and have to go around Unimak Island.

"I do not think that a float plane could land with a decent chance of survival at any point around the island, on account of the natural roughness and the sudden changes of the very strong currents. There is no place on the island for a plane to land except during certain days of the winter, when the snow forms smooth areas on the tundra. The beaches are simply masses of boulders.

"In 1942 an Army observation plane landed on the snow and took off again successfully, but only with the greatest of good fortune, and conditions which made that feat possible do not remain constant, on account of rains and thaws that occur thruout the winters.

"When we left Amak in 1943, in the fall, there were three usable structures on the island: a metal Quonset hut, an earth-covered dugout, and a tiny observation shack on the opposite side of the island; we left also a good well. I do not see why the well should not still be serviceable, altho it is not something to count on. The shacks are probably uninhabitable."

After study of Mr. Keenan's report, I wrote him as follows:

"Will you please elaborate on your statement that you 'would unhesitatingly affirm that the crater was caused by a falling object'? Did you draw such a conclusion from the resemblance the crater bore to the Meteorite Crater at Canyon Diablo, Arizona? Could you see rock strata turned up in the edges as at the Canyon Diablo Crater, or were the walls of the crater built up out of loose rocks like those that form the large mountains in the center of the island? Was there any evidence of the shattering and radial scattering of rocks as at the Arizona Crater, or any deposits of the peculiar rock flour found at Canyon Diablo, or any fragments of 'black glass' produced by melting of rock in the heat due to impact? Did you notice any sulfur deposits in or near the crater, or any crevicing of the ground radiating out from the crater? Are there any hot springs or steam vents in the neighborhood of the crater? Does water collect in the bowl of the crater, or is the rock so shattered (porous) that water drains rapidly away? Could you make any estimate of the age of the crater? Is there any noticeable difference in the vegetation growing in and near the crater and that elsewhere on Amak? *E.g.*, is the growth of moss less dense or of younger appearance in the crater than on the tundra? Do you recall whether the rock fragments in and about the crater were angular and sharp-edged, or were they smooth and rounded as if they had been weathered a long time? Did you by any chance bring or send home any samples of the country rock on Amak? If so, should you be willing to lend them to us for analysis?

"To your knowledge, have any meteorites or any fragments that might have been meteoritic been found on Amak or neighboring islands? Do you know whether the Aleuts made any use of metal, or were all their knives of slate, like the one you found? Did the natives have any legends about the descent of a ball of fire (Sun God) which made the crater?"

Mr. Keenan's detailed reply to my questions, under date of 1946 January 2, is quoted in full below:

"In answering the questions contained in your letter of December 26 I shall undoubtedly leave a good deal to be desired, on account of the fact that while on Amak I failed to realize that the very existence of

a possible meteorite crater would be a matter of some importance to science; also, the crater was so well known to the various soldiers who manned the island's outpost that it never crossed my mind that it was anything in the nature of a discovery. We had christened it 'Hollywood Bowl' and accepted it as an object of mild curiosity! However, I shall try to give some sort of answer to each of the questions.

"Most regrettable of all to me is the fact that I do not recall the designations of any of the air units then at Cold Bay. However, I have the address of one of our men now living in Seattle who can very possibly send you that information. As chaplain's assistant on the main post, he had some liason contact with most of the outfits at Cold Bay, and, in addition to this, he happens to be a person with a peculiarly retentive mind for details. Since I am writing him anyway, I will ask him to forward the information to you, in case he recalls it. I feel certain that just such photographs as you desire are in existence, if they can only be located. In this connection, the name of our commanding officer might be helpful. He was Lt. Col. J. G. Bennett, then in command of the 2nd Bn., 53rd Inf. I don't know his address, except that his home is in Mississippi.

"The reason I feel confident the crater was caused by a falling object is that it was made thru rather thick strata of soft dirt and gravel, as evidenced in the face of the adjacent cliff. In my mind it seems almost inconceivable that a subterranean eruption could have burst thru such a layer with sufficient violence to form a crater of that size without leaving greater evidence of the occurrence than the existing gentle and uniform slope of a few feet that surrounds the crater on all sides except where erosion has encroached. Wouldn't there have been of necessity some fairly spectacular heaping of volcanic rock in the immediate neighborhood, even if there wasn't an actual cone formed? And then, while it is entirely possible that a collection of alluvial earth thru the centuries might fill and smooth up the surface of a jagged hole until it resembled that particular one, I can't imagine it neatly preserving the form of the rim, which now resembles more than anything else a levee such as might be thrown up along the edge of a large irrigation ditch or excavated reservoir. I did think the crater bore some resemblance to pictures I have seen of the large one here in Arizona, at least in a superficial way.

"No, it was not possible to examine the surface of the crater without digging away the deep carpet of moss (about 1 ft., I think); so I can't say whether or not it showed pieces of glazed rock or volcanic ash or what. However, the ash was probably there anyhow, because it seems to underlie the top soil thruout most of that country.

"If I had only been less preoccupied with my poking around among the bone heaps on another part of the island, my curiosity would have led me to penetrate that moss in a place or two, just to see what sort of surface the crater did have, but, as it is, I am completely ignorant of what lies under it, and, what is worse, shall have to admit having failed even to walk down to the bottom of the depression to take a look! I do remember, however, that there were one or two large, rather angular boulders sticking up on the floor of it and that their dark color was about that of the other rocks common to the island.

"To my knowledge there are no hot springs or steam vents on the island. It is not likely that any such would have gone unobserved during the three years that the place was used for an outpost, even if I had failed to run across them myself. Since they would be a priceless asset to those staying at that desolate spot, they were probably sought for by the first arrivals, on account of the fact that they are to be found at places on the peninsula and other islands.

"There was no obvious difference in the moss carpet in the crater and that of other places, nor did the bottom look as tho it had ever held water, at least not for a long time.

"The only thought I had concerning the age of the crater was that it must have been there a long, long time in order to have so perfect a

hemispherical shape with the cliff so near. Of course, islands in the Aleutian chain have been known to raise or lower themselves overnight; so perhaps it was brought suddenly near the water's edge, and the erosion took place in a comparatively short time. The waves reach the base of the cliff only during violent storms.

"I have one piece of volcanic rock that I found at one of the old Aleut camp sites. It had been fashioned into a grinding stone, and, except for one other similar piece found in the same place, it seemed unlike any of the stones native to the island. It resembles black pumice, and I had supposed that it was brought in from elsewhere.

"The only samples I picked up were of some very red ore that appeared to me to be iron, but I didn't bring any home with me. They came from an exposed vein in a cliff on the other side of the island.

"Lots of whale bone and ivory spear and harpoon points were found in the bone piles, but I know of no metal ones nor of any of stone, except the one piece of knife blade I found, that I believe to be more ancient than the others, on account of its having been found beneath three separate layers of camp debris.

"Since it may convey some meaning to you, I will send the piece of grinding stone for your inspection.

"Finally, in answer to the last question, I have heard of no legends that might be connected with a falling meteorite, but that fact has little significance, since I heard of none on any other subject. The natives I met lived around the salmon canneries and had lost a good deal of their identity as a distinct race."

The specimen of rock promised by Mr. Keenan was received in 1946 January, and was very kindly identified for me by Dr. Vincent Kelley, of the Department of Geology of the University of New Mexico, who reported it to be "scoriaceous olivine basalt," thereby corroborating Mr. Keenan's identification of it as volcanic. Under date of January 23, I wrote Mr. Keenan as follows in regard to this specimen:

"I interpret your earlier statements to mean that the country rock on Amak, and in particular the rock in which the crater was found, is *not* volcanic rock like the specimen you sent me, and, in fact, that volcanic rock like your specimen was found only in the old bone piles in a part of the island remote from the crater. Is this understanding correct?"

Under date of January 27, Mr. Keenan replied as follows:

"In answer to your question about the piece of rock I sent, I can say that, aside from one other piece just like it, I saw no others of that type on the island. Of course that doesn't mean there aren't some there which I failed to notice. Both of the pieces I found were lying close to a big slab of whale bone that had apparently served as a sort of work bench, as there were all sorts of bits of tools and chips of ivory there too. I wish I had examined the face of the cliff near the crater and could tell you what sort of stones were imbedded in it, but I can't. I do recall, however, that the big boulders on the beach at that point looked just about the same as those at any other point around the island."

In spite of much additional correspondence and inquiry, no further facts concerning the Keenan crater have been uncovered. To date, I have heard neither from the Gardners at False Pass (*cf.* Keenan's letter of 1945 December 8) nor from the chaplain's assistant in Seattle (*cf.* Keenan's letter of 1946 January 2), and I have not been successful in securing photographs of the crater. Nevertheless, it seems unwise to delay longer publication of at least a preliminary account of the crater, in the hope that further important information will be sent me; for, on the one hand, there is need for haste in directing attention to the crater

before wave erosion damages or destroys it; and, on the other hand, developments in the international situation may at any time close the area in which the crater is located, to scientific expeditions. Therefore, on the basis of the information now available, an evaluation of the chances that Keenan's crater may be actually meteoritic, and, consequently, a worthy object of further scientific investigation, is attempted in the next and final section of this paper.

§5. *Conclusion.*—Because of the well-known abundance of volcanic formations in the Aleutian chain, it is natural to surmise that the crater reported on by Keenan is itself of volcanic origin. However, the statements quoted previously from Keenan's letters would seem definitely to negative this view. The closest volcano certainly identified as such is said to be distant 40 miles (or considerably more than the distance separating the Canyon Diablo Meteorite Crater from the nearest volcanic region). Furthermore, aside from a layer of what may be volcanic ash and two artifacts of volcanic rock recognized as such by Keenan and specifically stated to be quite distinct from the native rock on Amak, no materials of certainly volcanic origin are reported to be present on this island; but volcanic ash in great quantities is known to have been transported by winds over distances much greater than 40 miles, and Keenan's account makes clear that the two small fragments of scoriaceous olivine basalt, picked up by him at one of the old Aleut camp sites, differed so much from any of the country rock seen on Amak during his long tour of duty on this tiny island that he regarded them as having been brought in from elsewhere. Again, it seems that no hot springs, fumaroles, sulfur deposits, or other indications of volcanic activity occur on Amak Island. Moreover, Keenan's description of the crater lends no support to the hypothesis that it is of volcanic origin. His drawings and statements show that the bottom of Amak's "Hollywood Bowl" lies considerably below the level of the surrounding plain, whereas the bottom of a typical terrestrial volcano lies always considerably above the level of its surroundings.[3] Again, the discrepancy between the large volume of the hollow bowl and the small amount of material in and around its rim is emphasized by Keenan and is unfavorable to the hypothesis of volcanic origin, unless this is extended to include a single "phreatic explosion," such as is postulated to explain the so-called "maars" and other topographic features, some of which, like the Pretoria Salt-Pan, can certainly be more reasonably attributed to meteoritic impact.[4] Furthermore, the very perfect "hemispherical" shape of Keenan's crater, and the fact that the inner walls of the crater are considerably steeper than the outer walls, and the ratio of diameter to depth is near that observed in such authentic meteorite craters as those at Henbury, Australia, Kaalijärv, Estonia, and Canyon Diablo, Arizona, all favor a meteoritic rather than a volcanic origin.

Finally, in my opinion, it is particularly significant that Keenan stresses the artificial appearance of the crater's rim by stating that it "resembles more than anything else a levee such as might be thrown up along the edge of a large irrigation ditch or excavated reservoir." Precisely such descriptions have several times been given of features later proved to be the rims of meteorite craters. One may cite in this connection the Estonian craters and those of the Campo del Cielo, Argentina.[5]

On the whole, while recognizing that only detailed direct examination can definitely settle the issue, I am inclined to believe that the evidence supplied by Mr. Keenan is sufficiently favorable to the hypothesis of a meteoritic origin for

his crater to warrant further intensive investigation of this object. Since Mr. Keenan's suggestion that the crater was caused by the impact of a huge chunk of rock blown 40 or more miles by an exploding volcano cannot be taken seriously, the issue to be decided is simply whether the "Hollywood Bowl" on Amak was produced by the fall of a meteorite or by a single phreatic explosion. It should be possible speedily to settle this question by excavations uncovering the materials of which the walls of the crater are composed. An appeal is herewith made to all persons having access to Amak to carry out such excavations. Analyses and identifications will gladly be made of any specimens of the wall rock or of suspected meteoritic materials obtained by such explorations and submitted to the Institute of Meteoritics of the University of New Mexico. In conclusion, I earnestly request anyone having photographs of or additional information concerning the Amak Crater to communicate with me.

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[1] R. S. Dietz, "Geological Structures Possibly Related to Lunar Craters," *P. A.*, **54**, 465-7, 1946.

[2] F. G. Watson, *Between the Planets*, 170, Blakiston, Philadelphia, 1941.

[3] A. Wegener, *Die Entstehung der Mondkrater*, 13, F. Vieweg & Sohn, Braunschweig, 1921.

[4] C. A. Cotton, *Volcanoes as Landscape Forms*, Ch. 14, Whitcombe & Tombs, Ltd., Christchurch, New Zealand, 1944.

[5] L. J. Spencer, "Meteorite Craters as Topographical Features on the Earth's Surface," *Geog. Jour.*, **81**, 242, 1933.

Second Note on the Smithonia, Oglethorpe Co., Georgia, Siderite (0832,340)

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Since writing the note on "The Smithonia, Oglethorpe Co., Georgia, Siderite (0832,340)," in the February, 1947, issue of these CONTRIBUTIONS, I have received the following additional information concerning this meteorite from Director Clifford C. Gregg of the Chicago Natural History Museum (the depository of the specimen), which, thru his kindness, I quote:

"The meteorite was found at the foot of a hill about April, 1940, in a field in Smithonia (what used to be the Jim Smith plantation), Oglethorpe Co., Georgia, about 15 miles from Athens, Georgia. The coördinates were not given by the owner. At the time of finding the meteorite, the land belonged to one Mr. Benton, from whom the specimen was secured by Mr. Corbett Simmons. The Museum bought the meteorite from Mr. Simmons in September, 1942. It is a hexahedrite (H), and weighs 154 pounds. Its maximum dimensions are $20 \times 11 \times 7\frac{1}{2}$ inches, and it has the shape of an irregular, flattened cone. The original surface is eroded; the present surface is covered with platy oxides. The specimen is believed to be the entire fall."

The conspicuously crystalline and laminated character of the few heavily rusted but otherwise unaltered 26-gram fragments of the meteorite that are in my collection evidently confirms that it is a hexahedrite (H). Even from these fragments, the rather uncommon structure of the meteorite and its readiness to fracture with cubic cleavage are apparent.

The Smithonia siderite constitutes the eighteenth recorded meteoritic fall for the State of Georgia. Sixteen (16) of these falls are enumerated on p. 36 of

our "Catalog of Provisional Coördinate Numbers for the Meteoritic Falls of the World,"[1] while the seventeenth one is the Sardis, Burke-Jenkins Co.,[2] siderite, of which the C. N. = 0819,329; cl. = Og; and wt. = 1740 lb.[3] Of these 18 falls, 14 are siderites (Si) and 4 are aerolites (A). The only hexahedrite other than Smithonia is Holland's Store, Chattooga Co., (0854,344), which is a brecciated hexahedrite (Hb).

It may be of interest to add that the Smithonia meteorite was first brought to my attention by letter from Mr. Corbett Simmons of Elberton, Georgia, late in 1941, as a result of an article of mine on "Invaders from Space" in *Popular Mechanics Magazine*, **76**, No. 5, pp. 50-3 and 178, November, 1941.

REFERENCES AND NOTES

[1] *Univ. of New Mexico Publ. in Meteoritics*, No. 1, xiv + 54 pp., 1946.

[2] This designation means that the town of Sardis, for which the meteorite was named, is in Burke Co., while the place of fall is in Jenkins Co. *Cf.* the second par., footnote (6), p. viii, *op. cit.*, ref. (1), *ante.*

[3] Described by E. P. Henderson and C. Wythe Cooke in *Proc. U. S. Nat. Mus.*, **92**, No. 3143, 141-50, 1942. The longitude of the place of fall is given (on p. 142) as "80° 51′ 54″ W." This value seems to be in error by a whole degree; the longitude should probably read W. 81° 51′ 54″.

President of the Society: ARTHUR S. KING, Mount Wilson Observatory, Pasadena 4, California

Secretary of the Society: OSCAR E. MONNIG, 1010 Morningside Drive, Fort Worth 3, Texas

Comet Notes

By G. VAN BIESBROECK

There are no bright comets under observation at this time.

In the evening sky COMET 1946 *k* (BESTER) pursues its slow course through the constellation of the Fishes without much change in appearance. When last recorded here February 11 it was reduced to a small diffuse coma about 2′ in diameter with a well-marked but not stellar central condensation; there was an indication of a very faint tail in position angle 140° extending to nearly 5′ from the nucleus and a somewhat brighter extension in the direction 120° only half as long. The total brightness was estimated as 10^m2 on the Harvard Scale on that night which was four days after the computed perihelion date February 7.035 U.T. Since this comet does not come closer to the sun than 2.4 astronomical units, little activity is to be expected; besides the distance from the earth, which was 2.8 astronomical units on this date, continues to increases so that the luminosity will fall off. In March the comet will run into daylight and remain invisible for several months after which it will be greatly reduced in brightness.

In the second half of the night COMET 1946 *h* (JONES) moves into better conditions of visibility for northern observers but by March it will no longer be in reach with small telescopes. The two periodic comets, TEMPEL II and BROOKS, were recorded here in January but they were extremely faint and diffuse and no further observations can be expected at this return.

PERIODIC COMET SCHWASSMANN-WACHMANN 1925 II has been recorded several times in January-February as an extremely faint small coma and it is not likely that short outbursts of brightness might have happened in the gaps

of the observations.

Search for the expected PERIODIC COMET GRIGG-SKJELLERUP has been unsuccessful so far. The computed brightness for February 11 (see p. 111) was about 12th magnitude. Exposures showing stars as faint as 17th magnitude taken by the writer on that date failed to reveal the presence of the object. Unless the ephemeris requires a large correction the object is evidently still very faint.

Williams Bay, Wisconsin, February 13, 1947.

Communications and Comments

Under this heading we shall publish from time to time such material as does not properly fall under any of the established headings of this journal. Here, too, may be found, when occasion arises, articles which the editor may not be willing to give sanction to but which, nevertheless, may be provocative of thought along new lines.

A Conjecture on the Nature of Some Meteoritic Matter

In offering the hypothesis outlined herein the writer wishes to indicate that he is not a convert to his own speculations and realizes that, after all, such a hypothesis may be unnecessary. When sciences are young, very often, because of the lack of sufficient data and observation, certain phenomena seem to offer obstacles to a complete and satisfying hypothesis and seem to suggest that they themselves are due to different agencies and causes. Later these contrary phases of the young science fall under the scrutiny of research into the general, correct explanation. It is true also, however, that it is among such weaknesses and peculiarities in a general hypothesis that study brings to light new facts and discoveries, and it is well to test such weaknesses and unconforming phenomena by a variety of hypotheses. A young science that contains many such problematical aspects is meteoritics.

In the study of modern astronomy we encounter matter in every conceivable state. It is only in recent years that gases in the liquid and solid states have been accorded a place in astronomical hypotheses as, for example, in the ideas that the caps of Mars are solid carbon dioxide, that the gases on the outer planets are in solid and liquid states, and that even some of the satellites may be constituted of solidified gases. It has occurred to the writer that a certain class and percentage of meteoritic matter could very well be composed of gases in a solid state. With the adoption of this idea as a working hypothesis, explanations of certain meteoritic phenomena seem tenable. It is not to be construed, however, that all the suggestions outlined are, or could be, applicable, since that would make many of them mutually contradictory. Perhaps only one or two may stand out in a final analysis as worthy of consideration.

Many times have scientists stated that, could they only find meteoritic matter at the site of certain crater-like formations on the Earth, they could classify them as meteoritic craters. The hundreds of Carolina Bays present such a problem. Other places are the Pretoria Flats, Lake Bosumtwi, Köfels and Steinheim Basins, Nördlinger Reis, Kentland, Ind., Sierra Madera, Tex., *etc.* It is significant that at the site of the most recent meteoritic craters, those of the Siberian

fall of 1908, no meteoritic masses were found. Simply stated, such craters could be due to the meteorite's having been mainly a great mass or masses of solid hydrogen, nitrogen, oxygen, various chemical combinations of gases in the solid state as, for instance, of carbon dioxide and even ice. As a solid, the body would present all the characteristics of a mass of iron or stone striking the Earth, but of course there would be no residue to recover.

Such a hypothesis of solidified cosmic gases lends itself to the explanation of the phenomena of telescopic meteors. We might assume, for instance, that telescopic meteors are composed of solid hydrogen and are just as large as the brighter naked-eye meteors, granted that these are composed of the metallic or stony elements, but that they appear fainter merely because the hydrogen composing the meteorite does not provide as great a luminosity as does iron or other elements. The flame of a Bunsen burner is hardly luminous, yet it develops as much energy as a candle light, tho the candle light is far brighter. Again granting that a second-magnitude meteor is of the size of a pinhead, as most authorities state, it is difficult to visualize how small a particle a meteor of the twelfth magnitude, for instance, must be, and how such a tiny particle can excite to luminosity the vast extent of the atmosphere that it does. Regarding telescopic meteors as composed of tiny bits of solidified gases, which, when vaporized, provide a comparatively enormous volume of gas to become incandescent, seems better able to explain this aspect. The source of such hydrogen could be in our Sun or in the stars. Sheets of hydrogen escaping from prominences on the Sun and stars could condense in the cold of space and remain condensed, since solid hydrogen is diathermic. The high velocities of some telescopic meteors would be explained by this sun-and-star origin.

The estimates of the masses of invading meteorites are widely discordant. Assuming that meteorites in general consist of a large mass of solid hydrogen, with tiny particles of stone and iron imbedded in them, would provide a new basis for hypothesizing.

There have been conjectures as to physical differences between shower and sporadic meteors and bolides which drop meteorites. No meteorite has been established as coming from one of the great showers. It is possible to hypothesize, then, that shower or comet meteorites are composed mainly of particles of solid hydrogen that would be vaporized before they could reach the Earth.

There is a class of stones and irons which would be classified as meteorites if only they had surface characteristics of the known types of meteorites. These bodies have been found on mountains and in localities completely foreign to their constitution. There is no explanation as to how they could naturally happen to be there. If these bodies are meteorites their lack of surface markings can be explained by assuming that they were heavily coated with condensed gas which acted as a protective layer in the flight through the atmosphere.

Extraordinary heights of meteors have been reliably recorded at times. A particle of solid hydrogen would be expected to become luminous at a much greater height than a particle of stone or iron.

A good argument for the explanation of persistent meteoric trains can be upheld on the assumption that meteorites are mostly solid hydrogen and that bolides have a thick coating of such hydrogen. It has been difficult to explain how a tiny particle could excite a cylinder of the atmosphere 50 feet in diameter and 20 miles long. A cubic inch of solid hydrogen would be transformed into thous-

ands of cubic feet of hydrogen gas at a density sufficient to make it luminous thru electrical effects. As the hydrogen dissipates, the luminosity would disappear. A bolide train would be the super-cooled water-vapor cloud resulting from the combustion of oxygen from the atmosphere and hydrogen from the meteoritic body.

Since this hypothesis provides a basis for larger masses of meteorites, flickering meteors could be due to a highly irregular mass of solid hydrogen spinning thru the atmosphere. Another rare type of meteor, the nebulous or hazy kind, which has a very broad appearance, could be explained if it were considered to be of solid hydrogen.

As stated in the beginning, all of these suggestions could not be true, but perhaps, since it is reasonable to assume that some meteoritic matter may be solidified hydrogen, then one or two may be worthy of consideration. A close study will show that not a single well-settled fact has been assailed, and, on the whole, the idea of solidified hydrogen in space is a thought-provoking possible solution of many perplexing phenomena demanding explanation. Many other ideas follow naturally from these brief suggestions.

VINCENT ANYZESKI.

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General Notes

Miss Jessie May Short, for many years a teacher of mathematics and astronomy, at one time a member of the faculty and dean of women at Carleton College, died recently in Portland, Oregon, at the age of seventy-three.

Professor M. G. J. Minnaert, director of the Sonnenburg Observatory, Utrecht, has been awarded the Gold Medal of the Royal Astronomical Society for his outstanding contributions to solar physics and in particular to solar spectrophotometry. (*Nature,* January 25, 1947.)

Earle G. Linsley, Professor of Astronomy at Mills College, Oakland, and director of the Chabot Observatory in Oakland, has again been appointed the Alexander F. Morrison lecturer for the Astronomical Society of the Pacific. This is the fourth year that Mr. Linsley has been so honored. Professor Linsley's lecture for 1947 is titled, "Is the Sun an Exploding Bomb?"

Dr. Donald H. Menzel of the Harvard College Observatory was the speaker at a luncheon of the Minnesota Harvard Club at the University of Minnesota on February 25. Dr. Menzel discussed the work now being done on the sun at the station in Climax, Colorado. Dr. Menzel was then on his way to Colorado.

Minor Planets,—Dr. Paul Herget, director of the Observatory of the University of Cincinnati, is in charge of the work of the American Section of the International Astronomical Union related to minor planets or asteroids. This phase of astronomical research was seriously affected by the interruption of the work of the Rechen-Institut by the war. Dr. Herget and his associates will supply this lack, at least in part. Observatories which will assist in this work are: Yerkes, Lick, Warner and Swasey, Harvard, Dearborn, Kirkwood, U. S. Naval, and some others.

The Rittenhouse Astronomical Society, of Philadelphia, held its monthly meeting on February 14, 1947, in the Morgan Physics Laboratory, University of Pennsylvania. The speaker was Dr. Robert Fleischer of Rensselaer Polytechnic Institute, Troy, N. Y. His topic was "Probing the Milky Way."

The Cleveland Astronomical Society

Dr. D. A. MacRae of the Warner and Swasey Observatory addressed the February 7 meeting of the Cleveland Astronomical Society. He discussed one type of research work being done at the Observatory.

Dr. MacRae's lecture was well illustrated with many slides. He first gave the audience a general picture of the galaxy in which we live and the position of the Solar System with respect to the center of the galaxy. The audience was then shown what the Milky Way looks like in various directions as seen from the earth. Many details and the finer structures of the Milky Way were shown.

Dr. MacRae then showed how certain areas of the Milky Way have been photographed with the Schmidt-type telescope and studied in regard to the number, distribution in space, and magnitudes of the stars. These studies will make it possible to better determine the concentration of stars in certain areas and the distribution of the dust clouds or dark obscuring matter in space.

It was a very interesting lecture and we would like to have heard more about the work being done at the Warner and Swasey Observatory had time permitted.

HENRY F. DONNER.

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Interplanetary Communication

Until quite recently, discussions prompted by the above phrase were regarded as utterly fanciful. But now that radar contact with the moon has been made, such an outcome has seemingly been removed from the realm of the impossible. That interplanetary communication and interplanetary travel are receiving serious thought is attested by the existence of the British Interplanetary Society. Among the things which are specifically mentioned in the Constitution of the Society is the following:

> (1) To promote research into all branches of science which may have any bearing on the development of transport and communication both in regard to movement on the surface of the Earth, and from the surface to any other point on the Earth or in Space, and to conduct experiments for this purpose.

This Society also publishes the *Journal of the British Interplanetary Society,* now in its sixth volume. The issue for June, 1946, is of especial interest to American readers in that it contains an obituary of Dr. Robert H. Goddard, a pioneer from 1909 until his death in 1945 in the belief in the ultimate practicability of space flight.

Book Review

The World of Numbers, by Herbert McKay. (Cambridge University Press, The MacMillan Co. $2.50.)

"Explaining the World with Numbers" or "The World Examined by Numbers" would be titles describing more closely what is found in this book, a very fitting sequel to the author's earlier book "Odd Numbers" which dealt primarily with numbers as such.

No better description of the author's procedure in his examination of the world by numbers can be given than a quotation from the preface to his earlier book: "There are all kinds of interesting things that cry out for mathematical treatment. A few of them find their way occasionally into the newspapers; but few people seem to have any knowledge of what one may call educated arithmetic, the arithmetic that leads to results that are interesting in themselves. I have tried to make it clear that the surprising results we are sometimes shown—the apt illustrations given by astronomers and others—are not the result of mathematical magic, but of the ordinary processes of arithmetic. I have used nothing but . . . those parts of mathematics that are remembered by those who have not specialized in mathematics."

McKay's arithmetic is indeed educated. It ties up very deftly the size and speed of rivers with rainfall, floods, and erosion. It is conversant with such matters as the origin of the universe (last chapter). It speaks with confident defiance against statements made by H. G. Wells and George Bernard Shaw, to say nothing about finding inconsistencies in atlas tables.

McKay's style of writing carries an excellent continuity of interest. It also has an unburdened clarity. His chapter 2 might well be given as a reference to a science student who is slow in comprehending the matter of significant figures. The astronomy student having trouble with sidereal time need only read chapter 5.

All calculations are worked out in full detail, allowing the reader to follow all the steps without supplementation. The United States reader is reminded that Mr. McKay employs the word 'billion' in the English usage as 10^{12}, and 'trillion' as 10^{18}.

This reviewer finds fault with only a few items: There is confusion at the bottom of page 29 due to an incorrect antecedent. The use of e in two senses on page 19 might have been avoided. On page 10, semi-axes were meant instead of axes. For consistency of units the words 'per second' should have been omitted from the energy quantity at the top of page 37; this occurred, oddly enough, only six lines after the author refers to another's example and makes the statement: "I do not think 'an hour' should be there." Only one typographical error was noticed (page 72).

KENNETH W. WEGNER.

Carleton College.

POPULAR ASTRONOMY

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